

Methodologies for Processing Plant Material into Acceptable Food on a Small Scale – Phase II

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EXECUTIVE SUMMARY

1. Food processing is a technically feasible, effective part of manned space systems. Equipment suitable for processing food on a small scale, under zero-/micro-gravity conditions, have been developed and evaluated on a laboratory prototype scale.
2. Preliminary estimates indicate that while most nutrients can be met by the four crops studied in Phase II, it may be necessary to include an additional crop, such as Canola, which has about 2.5 times as much oil content as soy, to aid in meeting dietary fat requirements.
3. Daily planting/harvesting regimens increase personnel involvement, but reduce quantities of material to be processed, storage requirements, equipment sizing, energy requirement (present estimates indicate a possible maximum individual motor peak load of about 2 HP), and opportunities for automation.
4. Use of stable intermediate food products and food processing are compatible with both plant growth and preprepared food systems. They provide a feasible means of reducing the space requirements and packaging residue associated with portion-packaged foods.

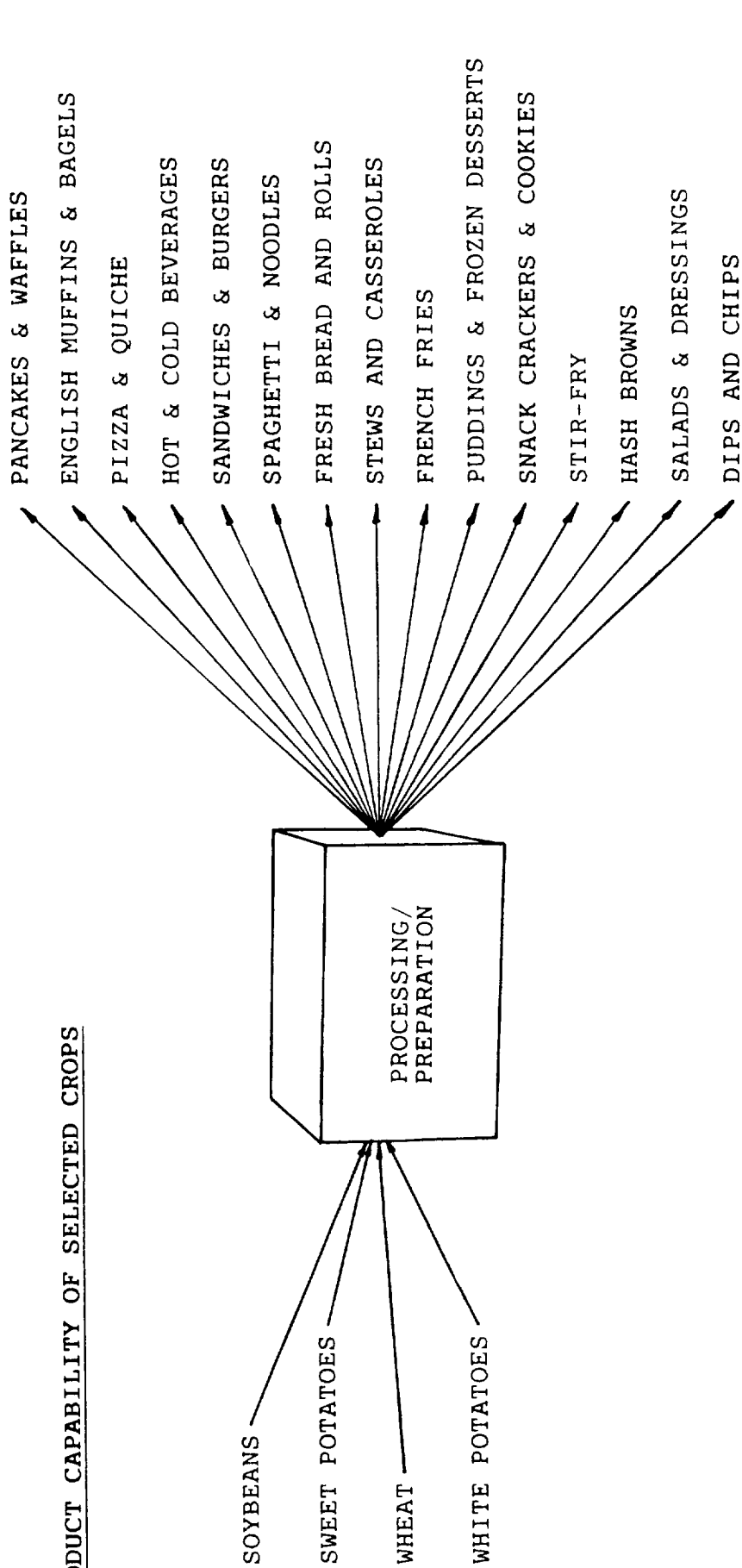
The four crops selected for this study, wheat, white potatoes, soybeans, and sweet potatoes, are capable of providing, with the addition of selected spices, flavors, acidulants, and other normal food ingredients, a broad and very acceptable menu. The figure on page iv shows a range of foods estimated producible from these crops under micro-/zero-gravity conditions. These and other products were prepared during prototype trials.

Products capable of being made from the selected crops were analyzed in terms of their equipment needs. Commercially available equipment was screened in terms of product and zero-gravity suitability. Where existing equipment was not available or could not be modified sufficiently, equipment concepts were developed and tested on a laboratory/prototype scale. The figure on page v contains a listing of equipment designed/tested. Patent applications are being prepared for approximately twelve of these concepts.

The figure on page v shows an overall material flow/unit operations analysis divided into processing areas, from harvest to products as eaten, including biomass processing, and indicating typical equipments required.

Harvesting decisions have significant ramifications on downstream operations, including: storage requirements, equipment sizing, energy needs, automation levels, and personnel involvement. Based on NASA nutritional guidelines and USDA Handbook 8, "Composition of Foods", it is estimated that daily processing quantities of the four crops selected for this project would be approximately as follows for a crew of twelve: *

PRODUCT CAPABILITY OF SELECTED CROPS



Complementing this list, the production of tempe and tofu from soybeans, and gluten from wheat enable space crews to make "hamburgers", "meatballs", and other meat analogs almost indistinguishable from their meat-containing counterparts. Other analog products include soymilk, yogurts, spreads made from soybeans.

EQUIPMENT CONCEPTS DESIGNED AND/OR PROTOTYPE TESTED BY FASI
DURING PHASE II

PARTICLE SIZE REDUCTION

Slicer/grater/dicer/fry cutter throat design *
Fry cutter configuration *
Bread slicer guide *
Biomass chopper
Mills for grains and dry beans

MISCELLANEOUS

Peeler *
Pancake/waffle pan *
Breadmaker/baker *
Trimmer/peeler
Soybean dehuller

HEAT TRANSFER

High air velocity oven configuration for increased production *
Combination oven
Steaming chamber for microwave and high air velocity ovens
Roasting system for wheat and soybeans
Freezing system for liquids

FOOD FORMING

Pasta extruder *
Pizza sheeter

MIXER

Dough mixer/kneader *
Dry solids and liquid mixer

DRYER

Louver Dryer
Inflatible Dryer

CLASSIFICATION/SEPARATION

Mass/inertia cleaner
Size separator

WASHER/DRYER

Washer/Dewaterer *

GRAIN/BEAN THRESHER

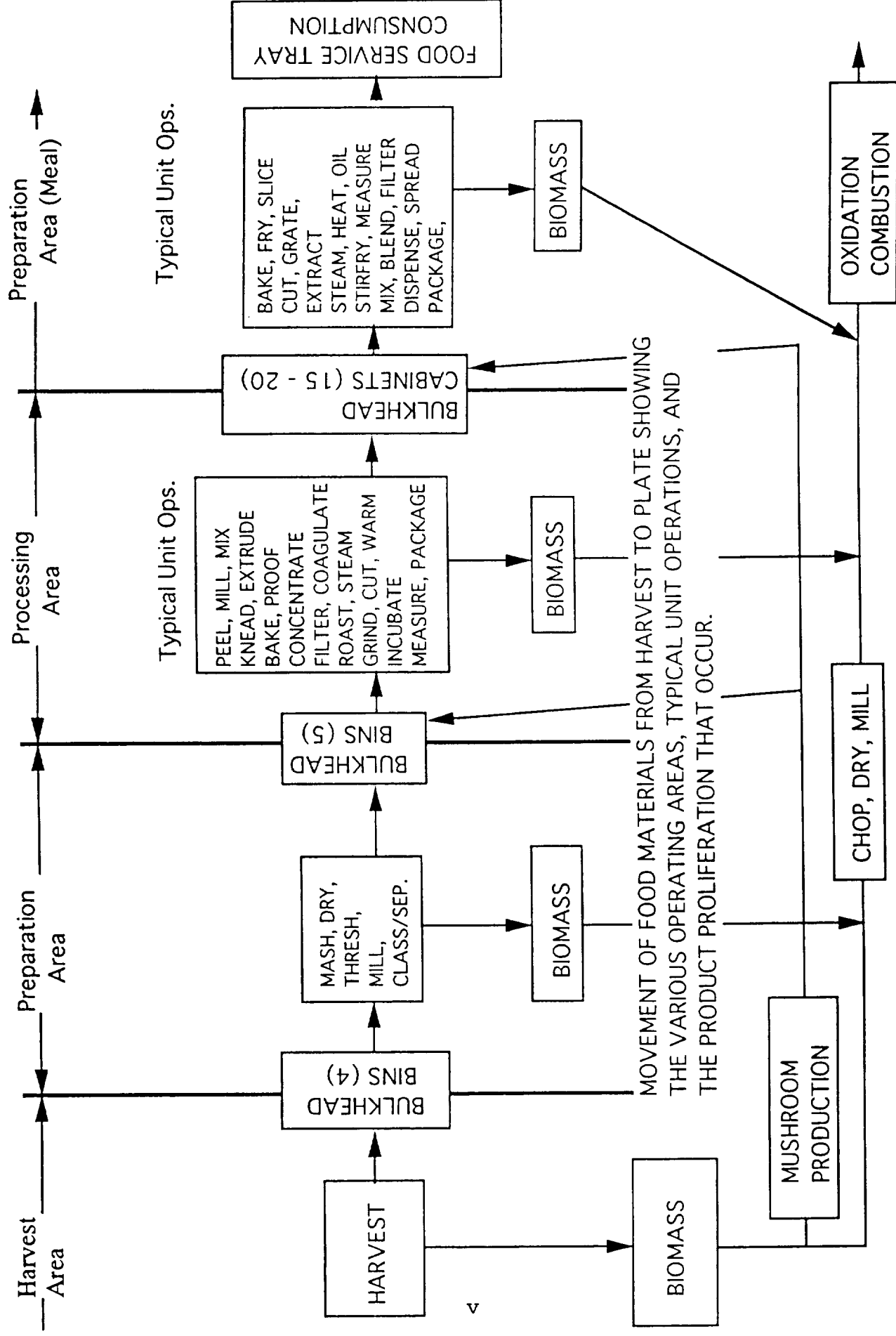
Impact thresher
Screen thresher (2 types)
Roller thresher for soybeans

MATERIALS HANDLING

Hot/cold beverage dispenser *
Liquid materials measuring and dispensing system
Dry solids measuring and dispensing system

* NOTE - Patent applications in process

Materials Flow Schematic



WHEAT -----	3.26 Kg
WH. POTATOES-----	5.86 "
SOYBEANS-----	3.10 " *
SW. POTATOES-----	2.80 "

* Note - These quantities provide only about 1/3 of the desired fat intake.

More specific information is needed about the nutrient content and functional properties of the various cultivars being developed under NASA's sponsorship. However, for the quantity range shown above, it would appear that storage bin capacities might range from 5 to 15 L, and that maximum individual motor peak load HP might be about 2.0. Less frequent harvesting would involve commensurately higher cube and weight penalties, and greater energy demand.

Current space food service is based on the use of portion packaged foods preprepared at Earth-bound facilities. This poses two significant problems: high cube requirement of some foods, and high cube devoted to storing packaging residues. Future long term space exploration and manned modules on bodies such as the moon and Mars will be required to produce food on site as missions extend beyond practical resupply limitations. In the interim, means are needed to reduce storage cube for food supplies and packaging residues.

A practical interim solution would involve the concept of stable, high density, intermediate food products, which would have reduced cube and packaging needs, reduced needs in terms of on-site processing equipment and energy demand, and high versatility in terms of menu application.

Stable intermediate products would be compatible and complementary to both on-site plant production and earth supply operational configurations, as shown in the figure on page vii; and could be produced by Earth-based facilities, or plant production/processing installations located on the moon or elsewhere, depending on the needs of the mission.

Preliminary estimations comparing the relative space requirements and feeding capability of providing ready to eat bread versus providing wheatberries and a breadbaking machine indicated that the on-site baking alternative could require approximately 37 L less space for a 30 day mission. For the same space, it was estimated that baking would produce sufficient bread for an additional 18 days. A proposal has been submitted to the IN-STEP Program to investigate the technical feasibility of baking bread in microgravity.

A Phase III extension of this project has already received initial funding to investigate new equipment concepts for processing soybeans. Discussions have begun with appliance manufacturers to fund two more Phase III extensions. Discussions with a third appliance manufacturer about a fourth Phase III will be initiated in the near future.

SCHEMATIC OF STABLE INTERMEDIATE FOOD PRODUCT UTILIZATION

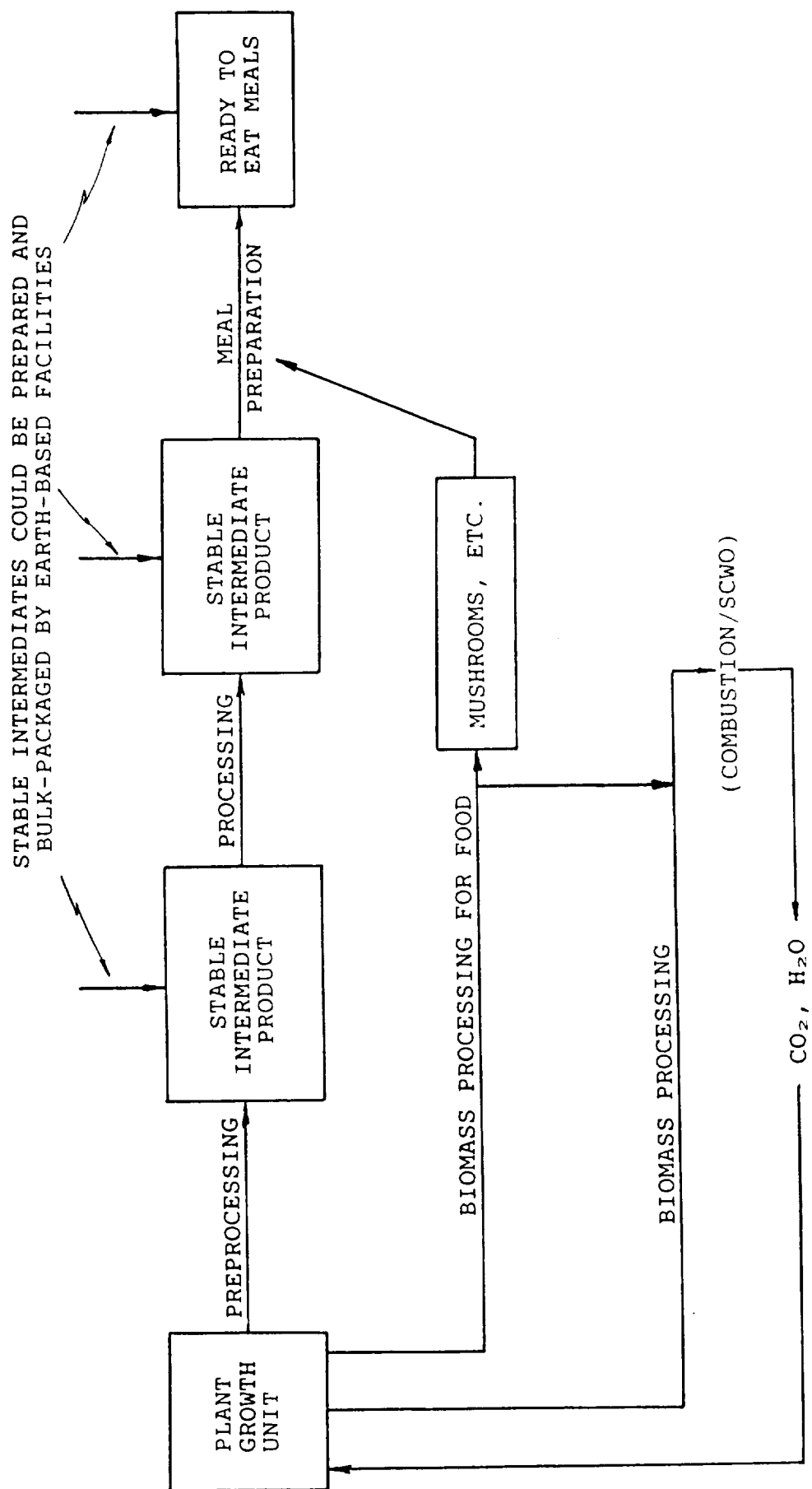


TABLE OF CONTENTS

Executive Summary.....	ii
Table of Contents.....	viii
Introduction.....	1
Description/Scope of the System.....	2
Project Objectives.....	5
Method of Approach.....	5
System Capacity/Capabilities/Constraints.....	6
Products and Processes.....	8
Process/Product Flow Diagrams.....	8
Unit Operations Summary Table.....	12
Establishment of Preliminary Menu.....	12
Discussion of Product/Equipment Needs.....	12
Materials Handling/Particle Control.....	22
Identification/Discussion of Commercially Available Equipment Suitable for CELSS Application.....	23
Homogenizer.....	24
Chiller/Heater.....	24
Freezer.....	24
Griddle(Waffle Iron).....	25
Mill(Flour).....	25
Mixer(Dry Ingredients).....	28
Dehull.....	28
Slice/Grate.....	29
KitchenAid/K-Tec.....	29
Cuisinart.....	29
French Fry Cutter/Dicer.....	30
Cuisinart.....	31
K-Tec.....	34
KitchenAid(Throat).....	34
Wedge Cutter.....	36
Mandolin(Boerner).....	36
Static Friction.....	39
Conclusions.....	41
Flaker/Cracker.....	41
Grinder/Chopper/Mincer.....	41
Dehydrator.....	43
Pasta Press(Pizza).....	43
Oven(Bake, Fry, Stirfry).....	43
Evaluation of the American Harvest Oven.....	49
Results of the A-H Cyclonic Testing Program.....	49
Cook/Steam.....	49
Bake.....	54
Fry.....	54
Pancake Production.....	55
Stir-fry.....	55
Puff.....	59
Toast.....	59
Roast.....	59
MicroWave Oven(Heat, Puff, Broil, Bake).....	60
Steam.....	64
Puff.....	65
Pancake Production.....	67
Proof/Sprout.....	67

Equipment Concept Designs, Prototype Trials and Design	
Modifications.....	68
Trimmer/Cutter.....	68
Peeler.....	68
Dryer/Thresher.....	80
Roller Thresher System for Green Soybeans.....	94
Wash/Dewater.....	95
Slicer(Bread).....	101
Mixer(Liquid and Dry Ingredients).....	105
Kneader.....	105
Dry Ingredient Measuring and Transfer.....	105
Hot/Cold Beverage Maker/Dispenser.....	109
Mass/Inertia-Based Classifier/Separator.....	115
Breadmaker.....	122
Liquid and Dry Ingredient Mixing.....	122
Kneading.....	127
Slicer/Grater/Dicer/Shoestring Cutter.....	130
Liquid Measuring System.....	135
Aspirator Tray Table.....	135
Bin Designs.....	138
Size Classifier.....	138
Biomass Processing.....	138
Biomass Processing for Combustion.....	138
Biomass Choppers.....	144
Dryer.....	149
Milling.....	152
Biomass Culture of Mushrooms.....	152
Mushroom Species.....	153
The Mushroom Production System.....	155
The Glovebox Work Station.....	156
Straw Collection Chamber.....	156
Autoclave and Pasteurization Chamber.....	157
Supplies Transfer Chamber.....	157
Agar/Grain Growth Chamber.....	157
Mycelium Vegetative Growth Chamber.....	158
Mycelium Primordia Growth Chamber.....	159
Wheat.....	160
Effect of Mature-Green Harvesting.....	160
Gluten.....	160
Dough Mixing.....	162
Alternative Baking Procedures.....	163
Pasta Production.....	165
Ingredients.....	167
Processing.....	167
Pizza Pressing.....	168
Soyfoods.....	171
Soymilk.....	173
Tofu.....	182
Tempeh.....	184
Edamame.....	186
Soy Sprouts.....	186
Processing by Extrusion/Expelling (Oil).....	187
Expeller Pressed Soy Oil.....	187
Whole Fat Soy Flour.....	189
Soymilk Beverages.....	189
Tofu-Based Meat Replacers.....	189
Tempe-Based Meat Replacers.....	190

Yogurt.....	190
Frozen Desserts.....	192
Textured Soy Flour.....	192
Extrusion Impact on Functional Properties.....	194
Materials Balance.....	196
Louver Dryer.....	197
Heat Transfer for the CELSS Food System.....	197
French Fry Production.....	201
Cutting.....	201
Frying.....	201
Use of the American Harvest Oven to Make French Fries.....	202
High Air Velocity Convection Oven Design Parameters.....	204
Air Flow Measurements.....	204
High Air Velocity Convection Oven Concept Design.....	205
Determination of the Mass of Objects in Zero Gravity.....	214
Automation Considerations.....	214
Materials Handling.....	216
Inventory Control & Menu Planning.....	216
Process Control.....	216
Operator Interface.....	217
Conclusions (Automation).....	218
Discussion, Conclusions, and Recommendations.....	218
Appendices	
Appendix A	
Evaluation of the American Harvest Jetstream Oven	
Using CELSS Ingredients	
Production of Ranch Fries.....	A-1
Production of Pizza.....	A-2
Preparation of Casseroles.....	A-4
Production of Pancakes.....	A-6
Preparation of Wheat Gluten "Meatballs".....	A-7
Production of Wheatberry Coffee.....	A-8
Production of Wheatberry Coffee II.....	A-9
Appendix B	
Preliminary Information on Making Puffed Snacks.....	B-1

INTRODUCTION

Due to enormous strides made in propulsion systems and vehicle design and construction, the limiting factor in man's exploration of space and other environments hostile to human life, is shifting to the systems and logistics of maintaining habitable environments and providing adequate food and water to support life and a level of morale conducive to achieving mission objectives. Heretofore, our explorations have been limited to durations that could be adequately served by bringing our environments and other requirements including food and water with us. As the bounds of our envelope expand, however, the systems and procedures involved in bringing our environments and food, etc. become increasingly cumbersome. Even with our current mission scope, packaging waste constitutes a problem. While the freeze-dry/compression technology developed by Natick Laboratories has been extremely helpful, this technique pertains only to certain types of foods, so that cube and weight are becoming an increasing concern.

Part of the solution to these problems lies in an examination of the forms in which foods are stored to select those which provide more efficient space utilization. Similarly, it may be necessary to re-examine those products which are inherently space wasteful. While it may be possible to position resupply modules for rendezvous with spacecraft on missions such as the Mars exploration series, selecting and processing food and packaging systems for maximum cube/weight efficiency, could not only extend mission capability, but reduce the number of resupply missions.

Even these techniques have their limits, however, with the result that long term habitation including extended duration missions will eventually need to incorporate the ability to convert waste and other materials into needed food, water, and air. The following report describes a NASA-sponsored phase II research program exploring the processing equipment/facilities/personnel implications of a system in which the principal nutritional requirements would be met by four plants: soybeans, white potatoes, sweet potatoes, and wheat. This research was based on the assumption that these crops could, indeed, be grown, harvested, and preprocessed(i.e., cleaned/separated from debris) in sufficient quantity in a CELSS environment under zero-gravity conditions.

A number of important operating parameters impact this program and the procedures recommended. One of the most important is the pattern of planting and harvesting. Planting/harvesting on a less frequent, i.e., monthly basis requires larger scale equipment and provision for packaging and storage, which pose greater weight and cube penalties, but enables more effective use of automation. Depending on the length of the growing period, this approach could also involve greater space requirement. Daily planting/harvesting involves smaller, lighter equipment with accompanying reduction in horsepower. Because of the availability of freshly harvested material, the need for storage is minimized. Depending on system design, daily planting/harvesting may perhaps tend to lessen the impact of possible crop failure. The major drawback to this approach might be potentially higher personnel

requirement. For the purposes of this research, NASA has indicated that current intentions are to plant and harvest on a daily basis.

DESCRIPTION/SCOPE OF THE SYSTEM

The very general scope of this program is as shown in Figure 1 which describes the overall flow of material from production to consumption, including the processing of biomass. In execution, however, the project team has necessarily had to undertake many tasks not envisioned in the original work plan, in order to accomplish the basic goals. The result is that the product of this effort has gone far beyond the determination of unit operations requirements, identification of equipment needs, and the development and testing of equipment concept designs. Other goals that have had to be accomplished along the way in order to achieve the prime objective, have included: identification of the product potential of the four crops selected, the development of menus, development of process flow diagrams, estimation of food quantities required to satisfy basic nutritional requirements, process investigations, and some basic product development.

It was very evident that either existing process technology, extraordinary equipment/support demands, or cost/benefit limitations, or combinations of the foregoing would not support certain processes in a CELSS. These included fermentation systems, and fats and oils refining and hydrogenation. In each of these cases a recommendation was made to suspend further consideration of the process within the scope of this program. Research is progressing rapidly in all of these areas, and in a few years the obstacles that precluded incorporation of these processes in this Phase II effort may have been overcome.

Harvest index, for the crops covered in this research ranges 50 to 70 percent, indicating very significant production of plant material which cannot be eaten because of digestibility or toxicity problems. While some of this material, such as wheat chaff can be used to produce food such as mushrooms and other fungi, by far the majority of inedible biomass would be combusted or wet oxidized to produce carbon dioxide for plant growth.

In terms of the overall system, crops grown for food/biomass would be harvested at the mature green stage. During this operation those fractions to be processed for food would be separated and aspirated to the PREPARATION AREA, while the remainder of the plant tissue would be coarse chopped and aspirated to the BIOMASS PROCESSING AREA. Harvesting at the mature green stage improves production efficiency by not tying up growth space while "field" drying occurs. In commercial practice, grains and dry beans would be sufficiently dry at time of harvest that threshing and harvest would be done simultaneously. At the mature-green stage, even though the beans and wheatberries will be fully developed from a nutritional standpoint, the bean pods and wheat heads will still be too flexible to thresh.

Based on this, the disposition of the various plant fractions at time of harvest would be essentially as follows:

WHEAT

Wheat heads	aspirate to PREPARATION AREA
Stalks and leaves	chop and aspirate to BIOMASS AREA
Roots	" " " " OXIDAT'N AREA

SOYBEANS

Pods containing beans	aspirate to PREPARATION AREA
Stems, leaves & Roots	chop and aspirate to OXIDAT'N AREA

POTATOES

Potatoes	aspirate to PREPARATION AREA
leaves, vines, and roots	chop and aspirate to OXIDAT'N AREA

SWEET POTATOES

Sweet potatoes	aspirate to PREPARATION AREA
Leaves and secondary stems	" " " "
Runners & roots	chop and aspirate to OXIDAT'N AREA

It is envisioned that materials aspirated to the PREPARATION AREA would be received in bulkhead bins. These bins would have a perforated bottom connected to an aspirator which would provide the conveying force, and at the same time would provide ventilation to reduce spoilage.

In the assignment of material to BIOMASS or OXIDATION, there is some measure of discretion. In biomass processing, the objective will be to utilize plant tissue that may be indigestible to generate edible food, such as mushrooms, and eventually, useful food ingredients such as yeast, citric acid, vinegar, lactic acid, and flavorings. At the present, the amount of plant tissue generated far exceeds the amount needed for production of mushrooms.

Oxidation or complete combustion provides rapid and efficient means of converting excess plant tissue back into the carbon dioxide, nitrogen, and water needed for plant growth, without going through the metabolic/respiration processes of humans and other organisms. This is especially desirable in the case of plant tissues which contain toxins. Potato plant leaves and stems contain a number of toxins, chief among which are chakonine and solanine. Investigations being performed by the USDA at their Western Regional Research Laboratories in Albany, CA would indicate these substances are extremely toxic even at very low levels to the trout larvae being used as the test organism. The degree to which these substances could be incorporated in foods such as mushrooms or yeast grown on potato plant tissue has not been investigated.

Thusfar, pending further development of zero-gravity fermentation technology, it is anticipated that only mushrooms would be grown on biomass; and that only wheat stalks and leaves would be used for this purpose, with the remaining plant tissue being relegated

Materials Flow Schematic

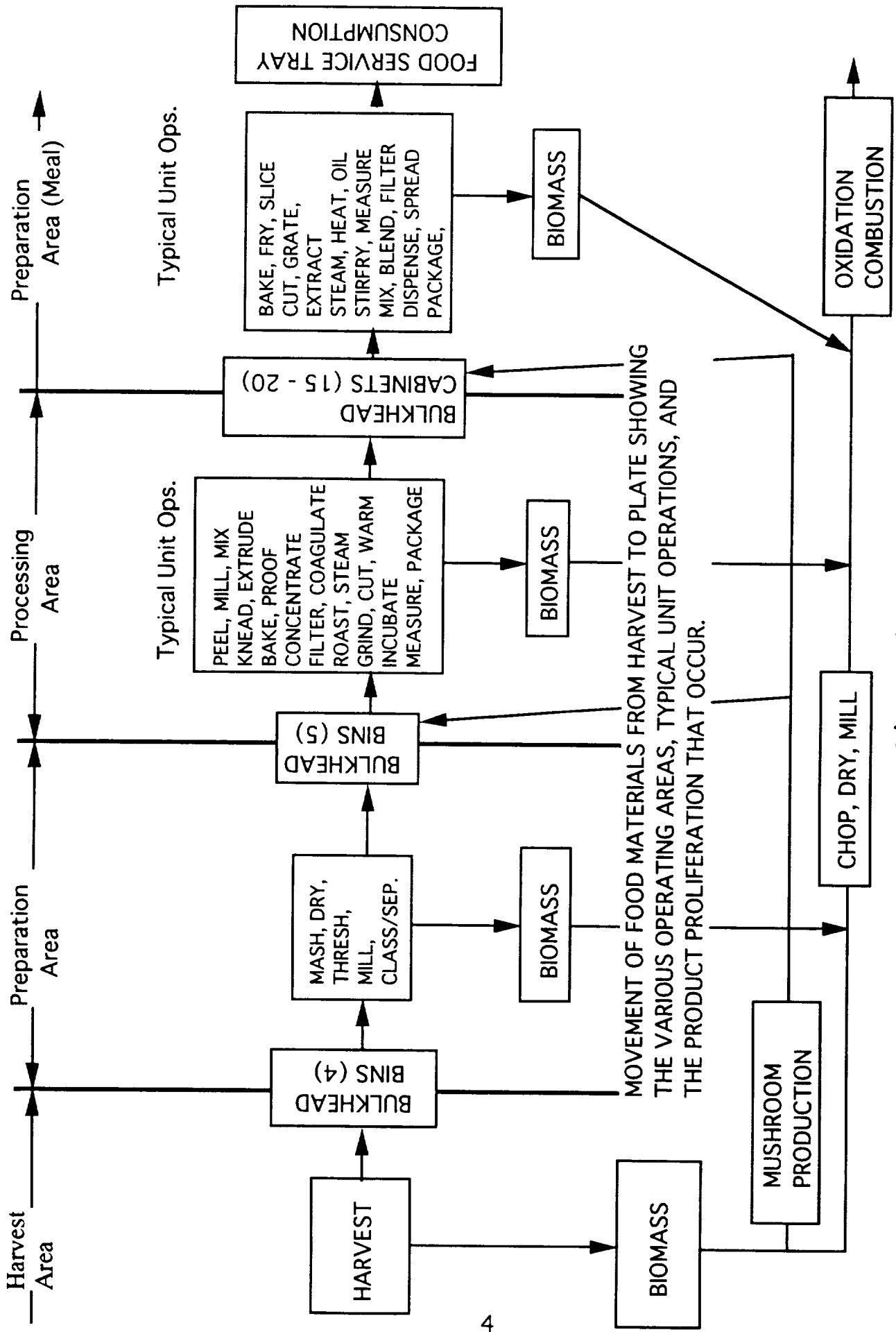


Figure 1

to oxidation or combustion.

This project starts when the materials are removed from the PREPARATION AREA bulkhead bins for preparatory processing or, in the case of the BIOMASS AREA, when the wheat stem/leaf material is inoculated with mycelia at the glovebox receiving chamber.

PROJECT OBJECTIVES

The specific objectives of this Phase II research project were as follows:

- a) Analyze and identify equipment requirements for the processing of soybeans, white potatoes, wheat, and sweet potatoes under zero-gravity conditions; and the production of mushrooms from wheat stem, chaff, and leaf biomass.
- b) Screen existing, commercially available equipment to identify those units suitable for CELSS operation under zero-gravity conditions
- c) Identify operational parameters of those unit operations for which no existing equipment appears suitable
- d) Develop concept designs to satisfy unit operation needs as required
- e) Construct and test selected concept designs on a prototype scale
- f) Redesign as needed to incorporate changes based on the results of prototype testing

METHOD OF APPROACH

To this point, all astronaut food service involved either direct consumption, or rehydration and warming of foods prepared and packaged on earth. No information was available on astronaut preferences with regard to foods that could be prepared from the selected crops, desired menus, or quantities of food required.

In the absence of this information, the project team took the approach of examining the food product/biomass potential of the four selected crops, selecting those products, procedures, and technologies adjudged suited to zero-gravity/CELSS conditions; and analyzing their unit operations requirements. These unit operations requirements were then interpreted in terms of equipment needs. Equipment capacity/throughput was estimated based on preliminary nutritional information provided by Dr. Bourland, Space Station Food-JSC. This equipment list was then screened to identify those items for which suitable units were commercially available, those items for which units were available, but which would need modification to make them suitable for zero-gravity/CELSS operation, and those items for which there were no suitable, commercially available units. For each equipment need that fell in this last category, the project team studied the process

parameters and developed concept designs to accomplish the necessary unit operation. In some cases this involved adapting and modifying existing equipment, in others, it required unique, new designs that could merit patent consideration. Some of the units from category 2 and 3 were selected for construction and testing on a laboratory prototype scale. Insofar as possible, prototypes were constructed of plastic to permit observation of particle behavior within the unit, and facilitate fabrication/modification. Based on the results of these prototype trials, changes were made as necessary to the concept designs.

SYSTEM CAPACITY/CAPABILITIES/CONSTRAINTS

To assist in the design and evaluation of processing equipment it is necessary to have information on anticipated throughput. To provide this, preliminary estimates have been made based on nutritional requirements contained in a draft report provided by Dr. Charles Bourland at NASA-JSC. Calculations based on meeting fat or protein requirements with soy results in imbalances difficult to rationalize. Preliminary calculations based on carbohydrate needs appear easier to work with, as follows:

Females:

18 - 30 years: $1.6(14.7W + 496) = \text{Caloric Requirement}$
30 - 60 years: $1.6(8.7W + 829) = \quad " \quad "$

Males:

18 - 30 years: $1.7(15.3W + 679) = \text{Caloric Requirement}$
30 - 60 years: $1.1(11.6W + 879) = \quad " \quad "$

Assume a crew of 12, and, to provide relatively higher capacity levels, that the crew will be composed of males less than 30 years old, and averaging about 83.9 Kg in weight.

Based on these assumptions, the caloric requirement per crew would be:

$1.7[15.3(83.9) + 679] = 3336.5 \text{ Calories (about 4 - 5\% higher than the estimated requirement at 1 G.)}$

Divided according to preliminary nutritional components as recommended by JSC, results in the following estimated daily intake per crew member:

PROTEIN REQUIREMENT

Protein to provide about 12 -15% of total calories consumed:

$(3336.5).15 = 500.5 \text{ Calories, @ 4 C/g} = 125 \text{ gms.}$

CARBOHYDRATE REQUIREMENT

Carbohydrate to provide about 50% of total calories consumed:

$(3336.5).50 = 1668.3 \text{ Calories, @ 4 C/g} = 417.1 \text{ gms.}$

FAT REQUIREMENT

Fat to provide about 30 - 35% of total calories consumed:

$$(3336.5).35 = 1167.8 \text{ Calories, @ } 9 \text{ C/g} = 129.8 \text{ gms.}$$

FIBER REQUIREMENT

Fiber requirement = 10 - 15 gms.

FLUID REQUIREMENT

Fluid requirement = 1 - 1.5 ml/Calorie

$$(3336.5)1.5 = 5004.8 \text{ ml} = 5.005 \text{ L}$$

PRELIMINARY ESTIMATION OF MAXIMUM REQUIREMENTS (No EVA)

COMPONENT	INDIVIDUAL	CREW(12)
Calories (Cal)	3336.5	40,038
Carbohydrate (gms)	417.1	5,005
Protein (gms)	125.0	1,500
Fat (gms)	129.8	1,557
Fiber (gms)	15.0	180
Fluid (L)	5.0	60

ASSUME:

45.0% of carbohydrate supplied by wheat
20.0% " " " " potato
16.3% " " " " sw. potato
18.7% " " " " soybeans

COMPOSITION DATA FROM USDA HANDBOOK 8

CROP	CHO(%)	PROT(%)	FAT(%)	CRUDE FIBER(%)	CAL(Cal)	H ₂ O(%)
Soy	33.5	34.1	17.7	4.9	403	10.0
Wheat	69.1	14.0	2.2	2.3	330	13.0
Sw. Pot.	26.3	1.7	0.4	0.7	114	70.6
Potato	17.1	2.1	0.1	0.5	76	79.8

CALCULATED AMOUNTS OF CROPS AND THEIR NUTRIENT CONTRIBUTION

CALCULATED AMOUNTS OF CROPS AND THEIR NUTRIENT CONTRIBUTIONS						CRUDE	
				CHO(gm)	PROT(gm)	FAT(gm)	FIB(gm)
WHEAT	$\frac{(5005)(.45)}{.691}$	= 3259.4 gm		2252.3	456.3	71.7	75.0
POT.	$\frac{(5005)(.20)}{.171}$	= 5853.8 gm		1001.1	122.9	5.9	29.3
SW. POT.	$\frac{(5005)(.163)}{.263}$	= 3102.0 gm		815.8	52.7	12.4	21.7
SOY	$\frac{(5005)(.187)}{.335}$	= 2793.8 gm		935.9	952.7	494.5	136.9
		TOTAL		5005.1	1584.6	584.5	262.9

Based on these assumptions and the consequent nutrient contributions, only about 30% of the total fat requirement would be provided by soy. The remainder would need to come from other sources, such as rapeseed (Brassica).

CALCULATED PROD'N, BULK DENSITY ESTIMAT'N, & EST. STORAGE NEEDS

CROP	EST'D DAILY PROD'N NEEDS (gm)	EST'D APPROX. BULK DENSITY (cc/Kg)	EST'D APPROX. STORAGE NEEDS (L)
WHEAT	3260	1214	4
POTATO	5855	2428	14
SW. POTATO	3100	2483	8
SOYBEANS	2795	1312	4

PRODUCTS AND PROCESSES

While the objective of this program is to identify equipment suitable for CELSS operations and develop processing equipment concept designs, it is imperative to know what products these machines will need to make, the starting materials, and the production rates necessary. In the absence of specific guidelines on astronaut food preferences, information was sought on the experience gained from extended submarine missions. Preliminary information indicated boredom to be a significant factor, and that familiar, home-type dishes might be more acceptable than more fancy fare. Similarly, it was indicated that foods that tended to break up the routine eating pattern, such as snacks and hors d'oeuvres seemed to have a positive effect on overall food consumption. Accordingly, effort was devoted to identify snack and cookie-type products that could be conveniently eaten without utensils, and dessert type products such as frozen yogurts. Emphasis was also placed on familiar products such as pastas, baked goods, and pancakes.

Within those general guidelines, an analysis was undertaken to establish a list of foods that might be prepared from the stipulated four crops. Figure 2 shows the results of this examination. It should be understood that the purpose of this exercise was not to identify every specific product, but to identify the product types to aid in identifying unit operations parameters/equipment needs.

PROCESS/PRODUCT FLOW DIAGRAMS

Based on the results of the analysis shown in Figure 2, flow sheets were created for each of the four selected crops identifying the processing pathways needed to make the various products selected, and the unit operations involved.

While not all CELSS operating conditions have been established, some preliminary examination was devoted to the technical feasibility of these operations. Specific concerns included the suitability of existing technology, potential processing problems, the "cost"/benefit of the process versus the likelihood of being able to develop a less troublesome alternative, and the potential cube/weight involvement. A correlated, but also very important factor, is the need to be realistic about the development of food processing capability aboard CELSS. Initially, these processes should be selected based on such attributes as simplicity, versa-

POTENTIAL PRODUCTS

VEGETABLES	MEAT SUBST.	SALADS	BAKED GOODS	BREAK- FAST	SIDE- DISHS	SNACKS	DESSERTS	BEVERAGES	INGREDIENTS
<u>WHEAT</u> steamed wheat sprouts bulgur steamed wheat	wheat gluten	wheat sprouts	bread rolls biscuits donuts bagels bread- sticks dumplings muffins crackers	wheat flakes waffles pancakes puffed wheat toast	pasta	puffed wheat snack crackers	cookies cake	imit. coffee	wheat flour wheat starch wheat gluten
<u>SW. POTATO</u> mature leaves baked sw. potato candied sw. potato mashed sw. potato fried sw. potato steamed sw. potato		immat. leaves second. stems				sw. pot. chips sw. pot. puffs	sw. pot. cake		sw. pot. flour sw. pot. syrup
<u>WH. POTATO</u> baked potato mashed potato potato pancakes hash browns french fries sauteed potatoes		potato salad				peel chips potato puffs puffed chips			potato flour potato starch. dextrose

Figure 2

POTENTIAL PRODUCTS (continued)

VEGETABLES	MEAT SUBST.	SALADS	BAKED GOODS	BREAK FAST	SIDE DISHES	SNACKS	DESSERTS	BEVERAGES	INGREDIENTS
SOYBEAN									
steamed	tofu	soy		puffed		soy	soy ice	soy milk	soy flour
immat.	tempe	sprouts		soy		yogurt	cream		soy oil
leaves		immat.		flakes		toasted			
steamed		leaves				soybeans			
pods		immat.				toasted			
fried pods		pods				soy snack			
steamed						crackers			
mature						soybean dip			
beans						imit. cheese			
steamed									
sprouts									
steamed									
immature									
beans									
(edamame)									

Figure 2 (cont'd)

tility, reliability, and weight/cube penalty. As these more simple processes prove their value, more complex processes and operations can be added.

Based on this evaluation, particularly because of anticipated changes to existing technology, further consideration of a number of products/processes has been postponed. These include;

- Production of oil and oil-based products from soybeans
- Vegetable oil refining and hydrogenation refining
- Fermentation processes such as for production of vinegar, yeast, citric acid, lactic acid, and certain gums.

In the case of expelling oil from soybeans and the manufacture of products such as shortening and margarine, the considerations examined included the fact that the most valuable contributions of the soybean are its protein, and the contribution it makes in terms of meat and dairy substitutes, beverages. These include: tempe, tofu, soymilk, and a whole range of yogurt-based products. In a fully dried soybean, the oil content is only about 18 percent compared with about 40 percent for oilseed sources such as Canola. Because of the emulsifying action of phospholipids, the oil must be removed by expelling which requires fairly heavy equipment for the amount of material being run and the yield obtained. The temperature reached by the beans during the expelling process causes changes to the protein which jeopardizes the production of tempe, tofu, and soymilk.

An additional factor which pushed in the direction of postponing further consideration of expelling and processing soy oil was the fact that soybeans grown under CELSS conditions, as currently planned, will be harvested at the mature-green stage. These can be dried in the pods completely and then threshed, or dried only sufficiently for threshing. Drying in regard to soybeans normally consists of field drying preparatory to threshing, and whatever might occur for storage. The minimum degree of drying required for production of tempe, tofu, and soymilk has not been defined, and would require detailed experimentation beyond the scope of this project.

Fermentation was set aside as an active part of this Phase II research because most of the processes that would be useful required aerobic conditions, where foam production would be extensive, and almost impossible to get rid of under zero-gravity conditions. The most desirable products for these fermentation systems were vinegar, yeast, citric acid, and lactic acid. Vinegar would be useful as a flavoring and acidulant for use in dressings and sauces, etc. Yeast is valuable for its protein content as well as a flavoring. Citric acid would facilitate the production of soft drinks for astronauts in a CELSS, and lactic acid fermentations could improve the ability to make cheese substitutes. None of these products/processes are essential to basic CELSS operations; however, as CELSS systems become more sophisticated, their addition could be desirable. Because of this and the fact that redesigning fermentation systems to eliminate foam for zero-gravity operation was considered outside the scope of Phase II operations, it was decided to defer further work on fermentations

for future SBIR proposals. Were the operating conditions to shift from zero-gravity to a reduced-gravity situation such as might be posed by lunar sites, most of the difficulties anticipated for fermentations, i.e., foaming, would be much less of a problem. Even in zero-gravity, research is being performed on fermentation process technology, so these technologies may become well defined over the next few years.

Figures 3a, b, c, and d are process flow diagrams for soybeans, white potatoes, wheat, and sweet potatoes respectively, identifying various products which could be made from these crops, and identifying the principal unit operations that would be involved. Figure 4 combines these individual flows into integrated flow diagram identifying operations by whether they occur in the Pre-preparation, Processing, or Preparation Area.

SUMMARY UNIT OPERATIONS TABLE

Figure 5 presents the results of an analysis summarizing the data of Figures 3a, b, c, d, and 4 to show the scope and estimated throughput range of products/materials involved in each unit operation. The purpose of this information was to aid in selecting and evaluating alternative commercially available equipment for their suitability to cover the range of products needed.

ESTABLISHMENT OF PRELIMINARY MENU

Figure 6 is a preliminary menu based on a three week cycle based on the analysis conducted in Figure 2 and the products identified in the flow diagrams shown as Figures 3a, b, c, and d. Although the objective of this project was to develop equipment concept designs, it was felt necessary to develop a menu for two important reasons: 1.) it provided a check on the adequacy of the four crops selected to enable sufficiently diversified products, and 2.) by identifying a wide range of products having different unit operational requirements it provided a practical check that potentially important unit operations had not been omitted.

DISCUSSION OF EQUIPMENT NEEDS

Commercial powered equipment is usually designed for a single operation. Most of it is unsuited to the envisaged requirements of a space station primarily because capacity is way in excess of the needs of a twelve man crew. Equipment for the retail trade, on the other hand, is designed for smaller quantities in the range of NASA's needs. Also with the various attachments available for the more expensive all-purpose types, the units are versatile.

There are three basic types distinguished by the rotational speed of their primary functions.

Soy Beans

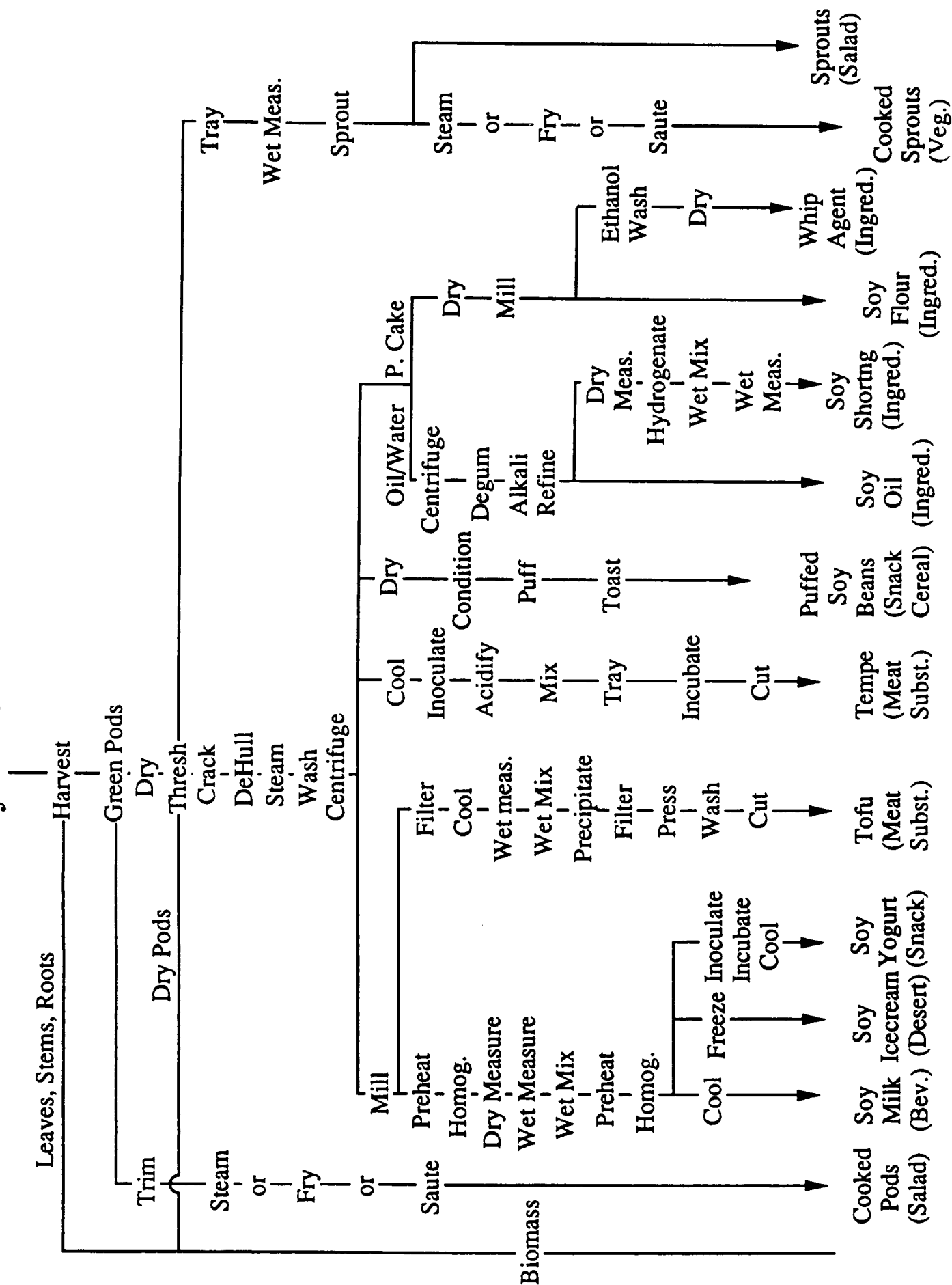


Figure 3a

Potato Plant

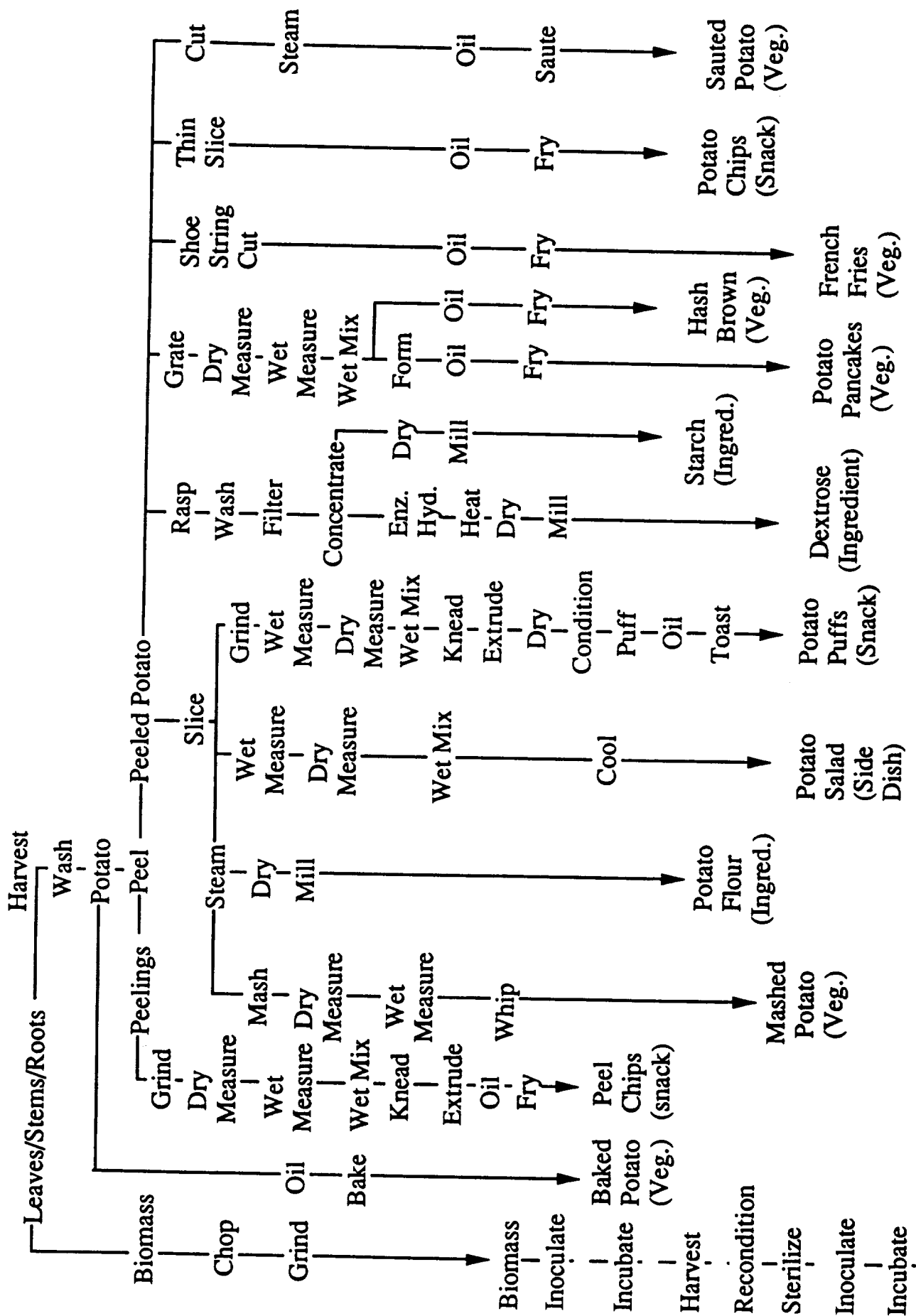


Figure 3b

Sweet Potato Plant

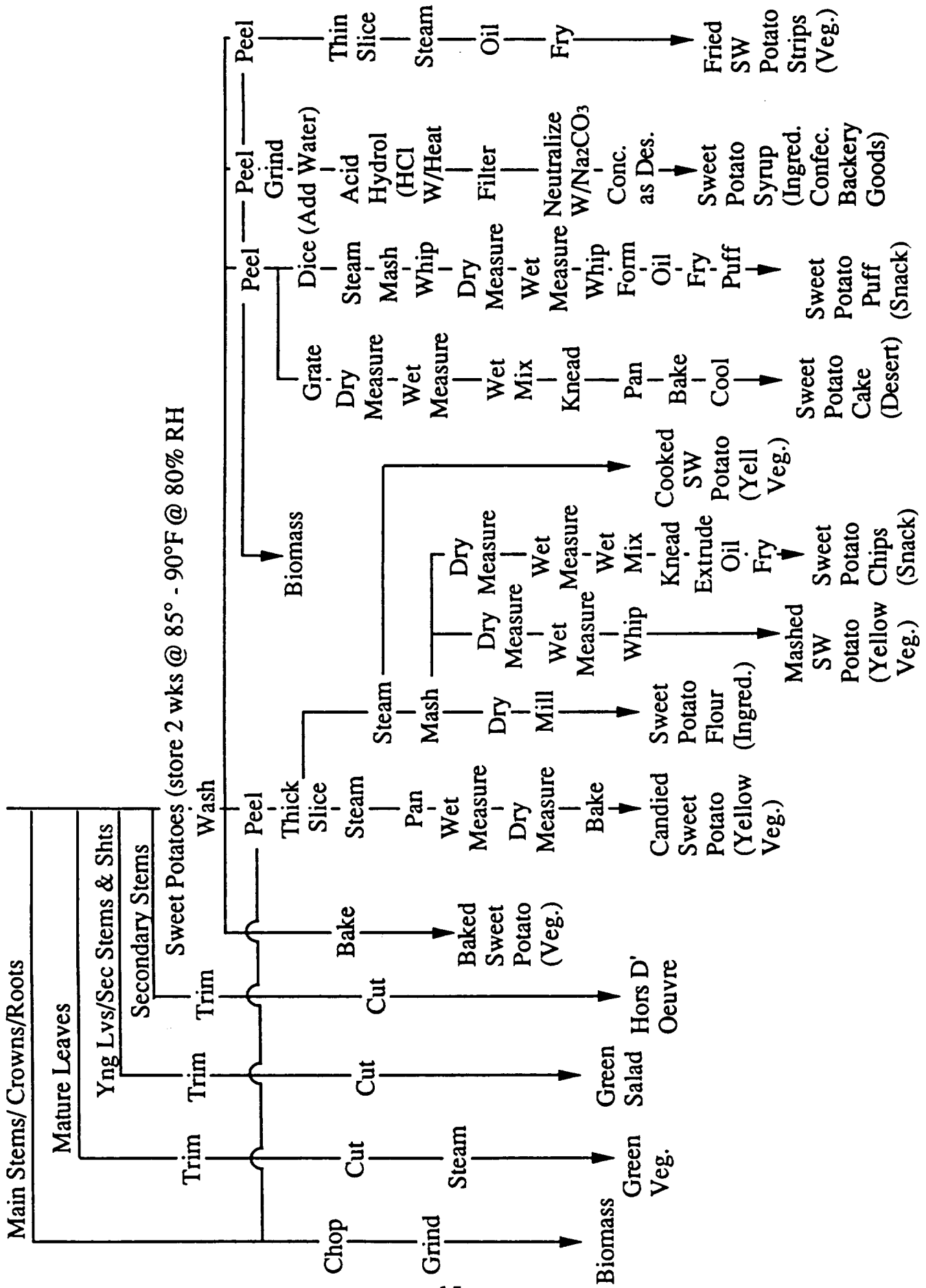


Figure 3c

Wheat Plant

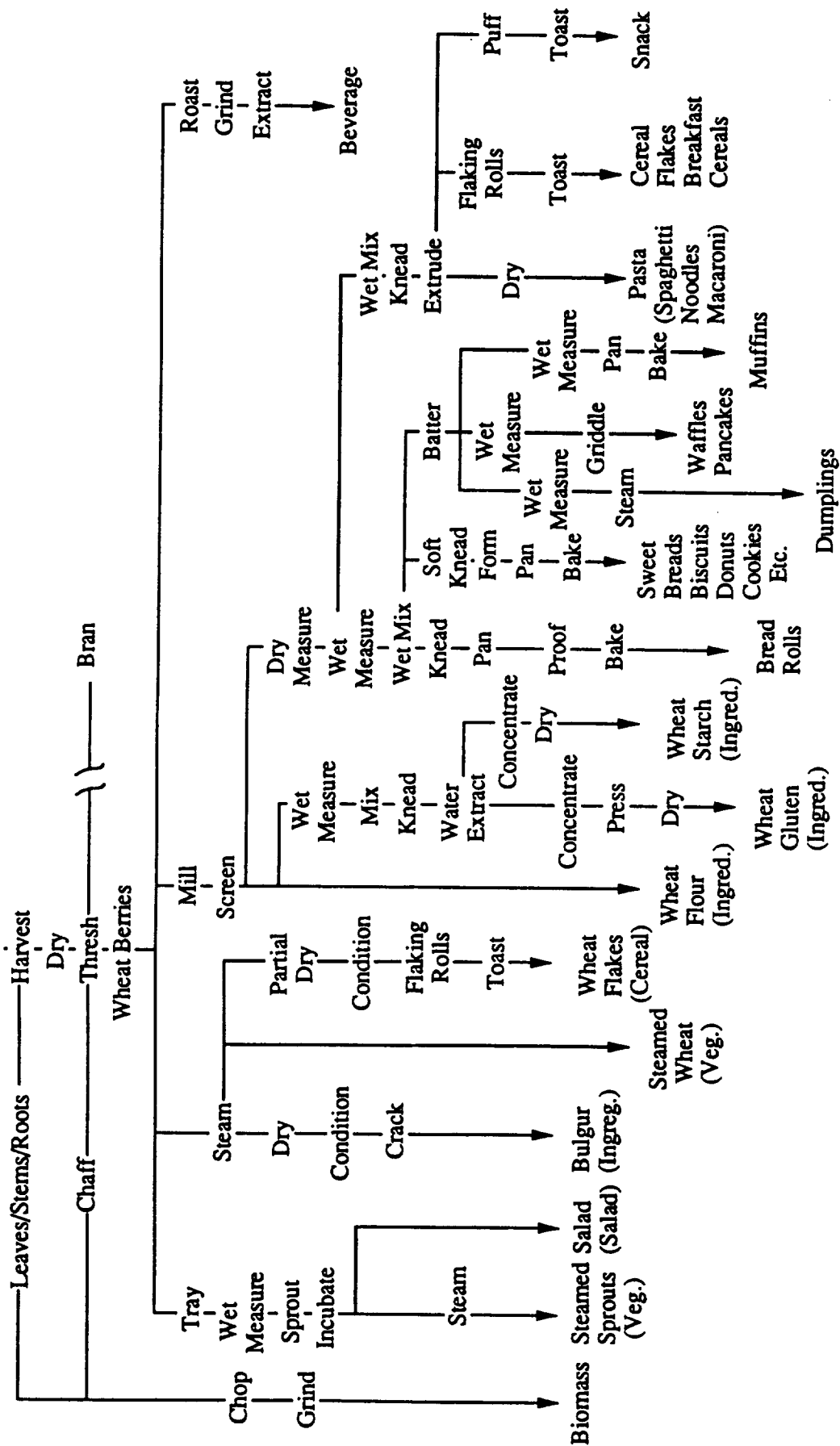


Figure 3d

FOLDOUT FRAME

AREA 1

Prepreparation

Mission: Prepare mtl's rec'd from harvest for processing

AREA 2

Processing

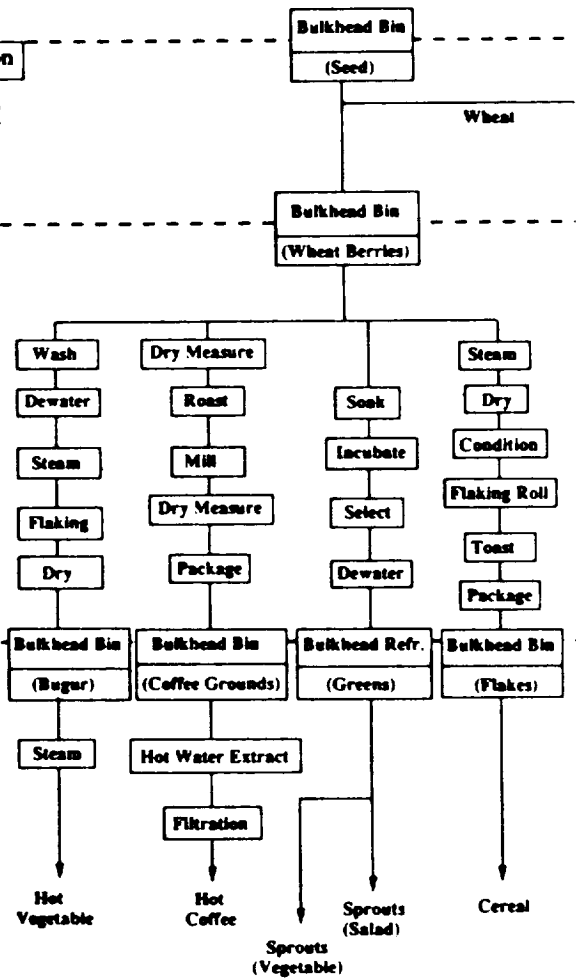
Mission: Process raw mtl's to a stable form ready for use

AREA 3

Preparation

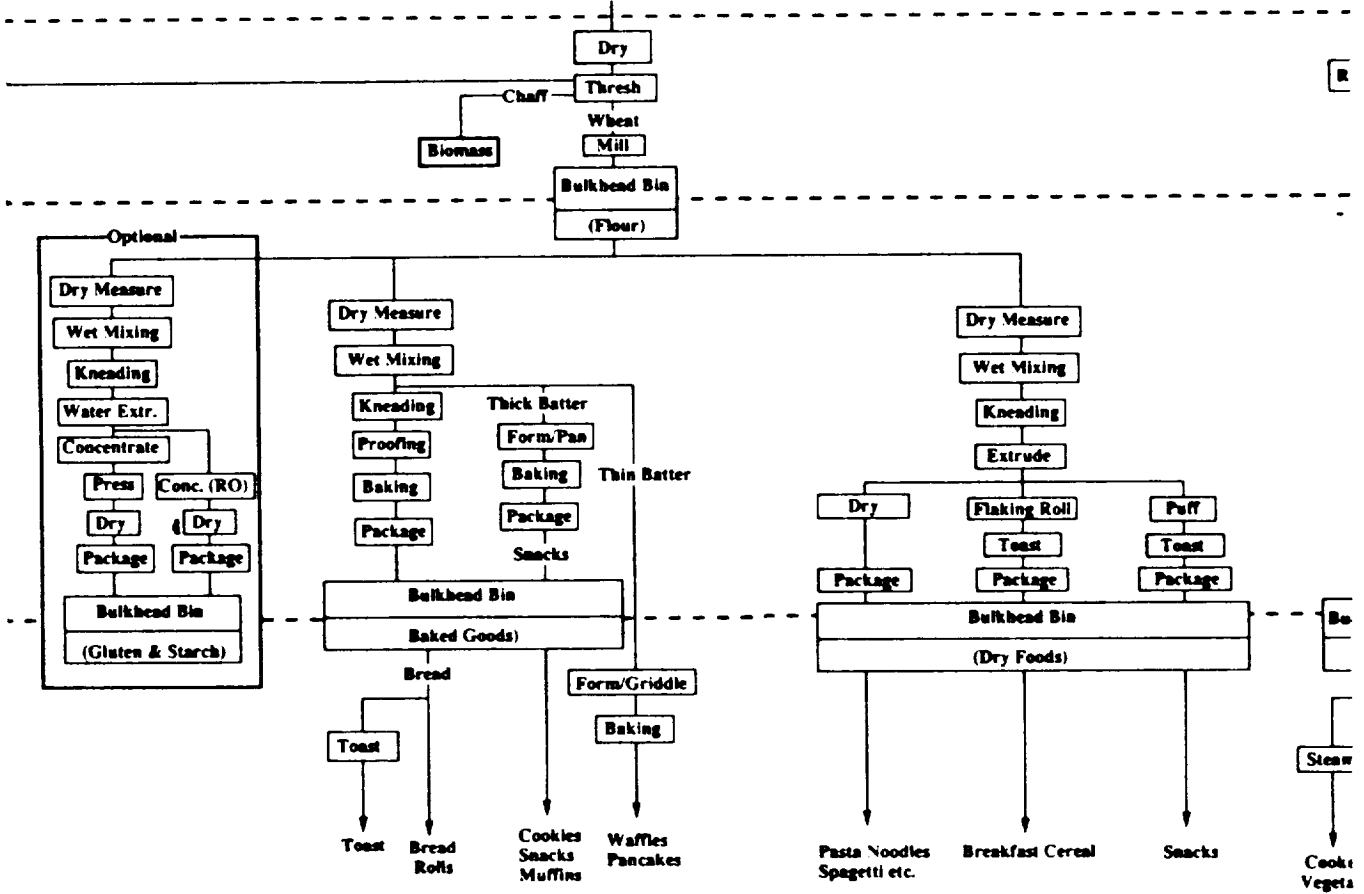
Mission: Prepare meal elements for meals or storage for future consumption

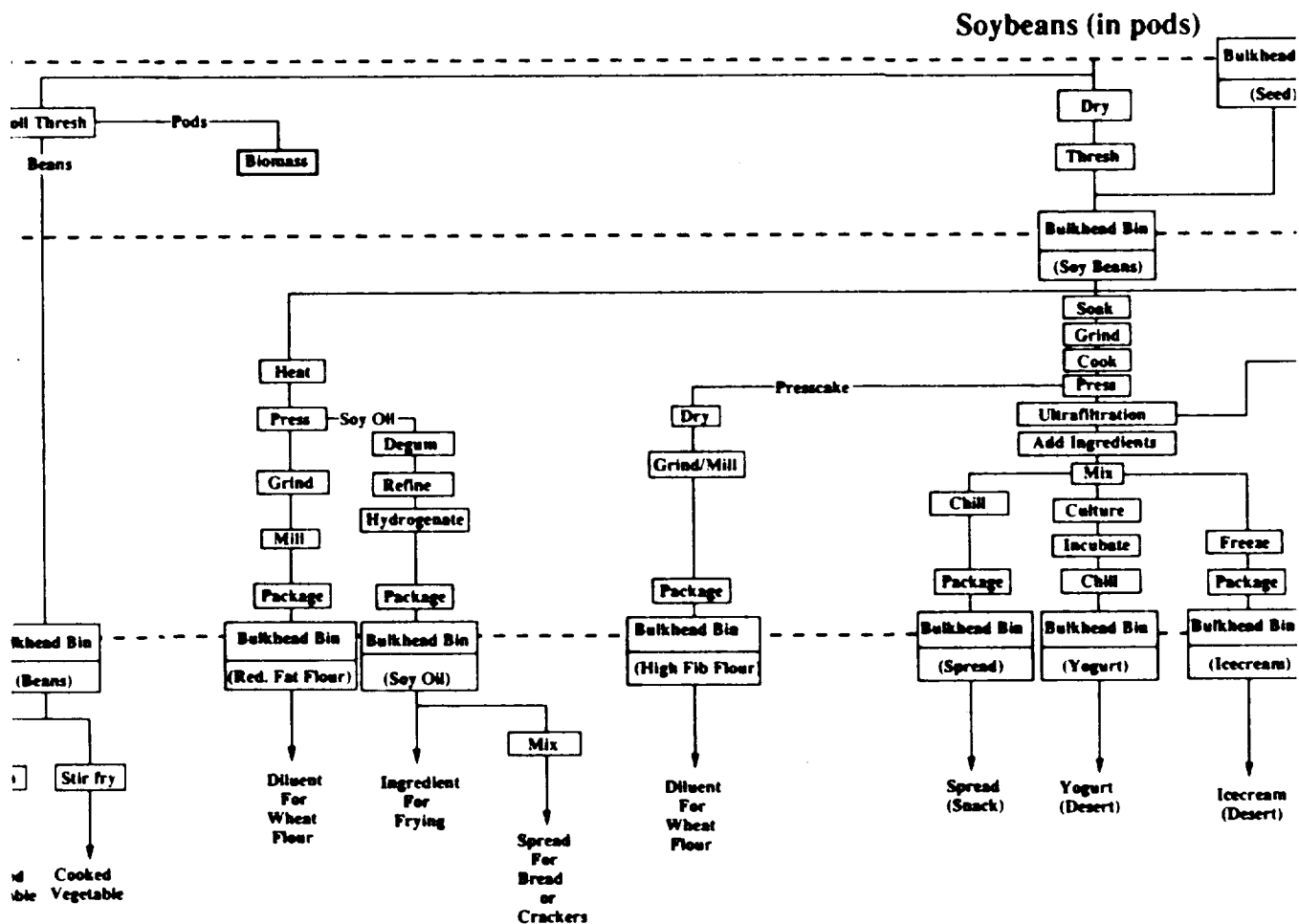
AREA 4



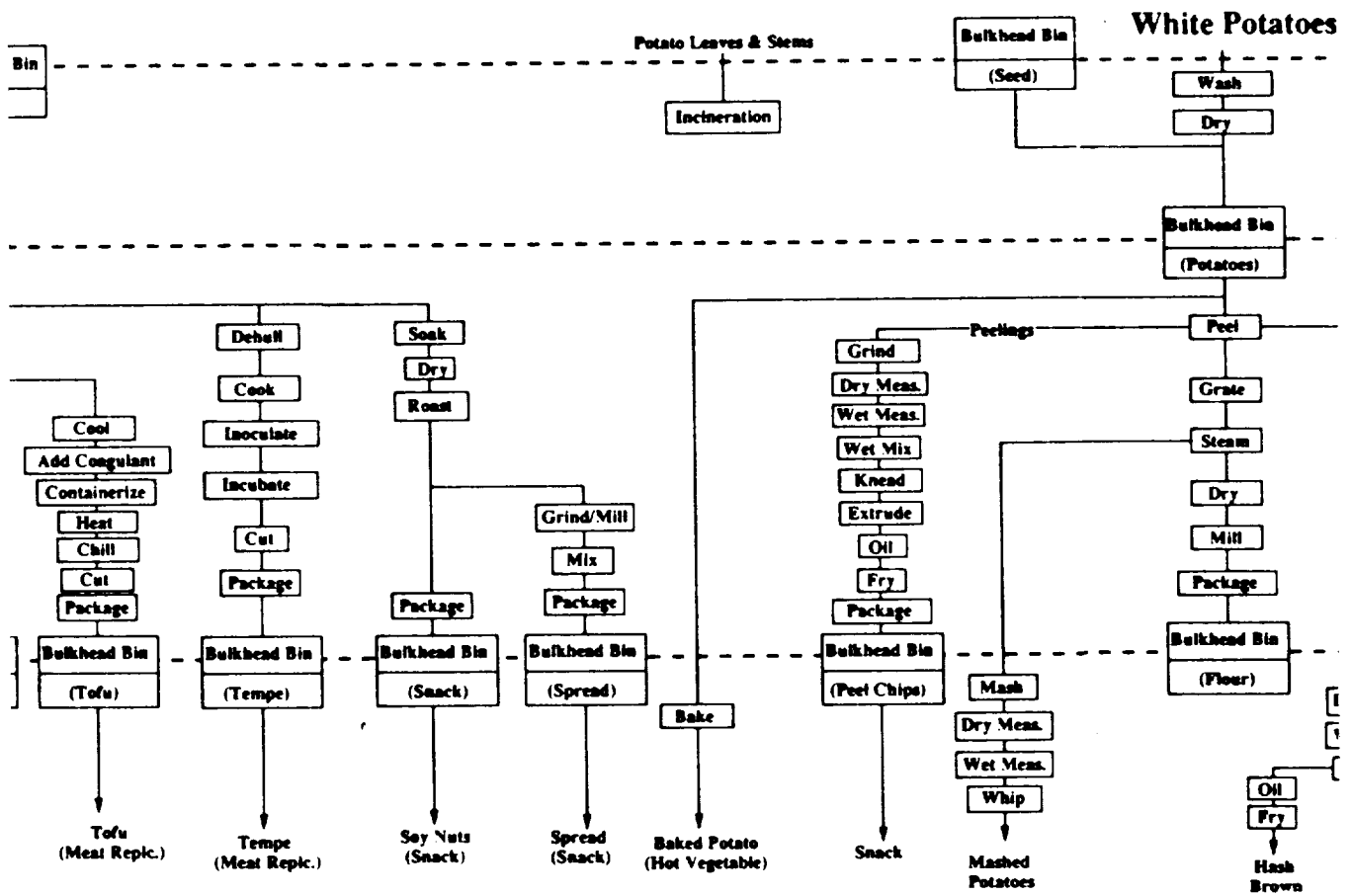
FOLDOUT FRAME 2.

Wheat Heads





FOLDOUT I



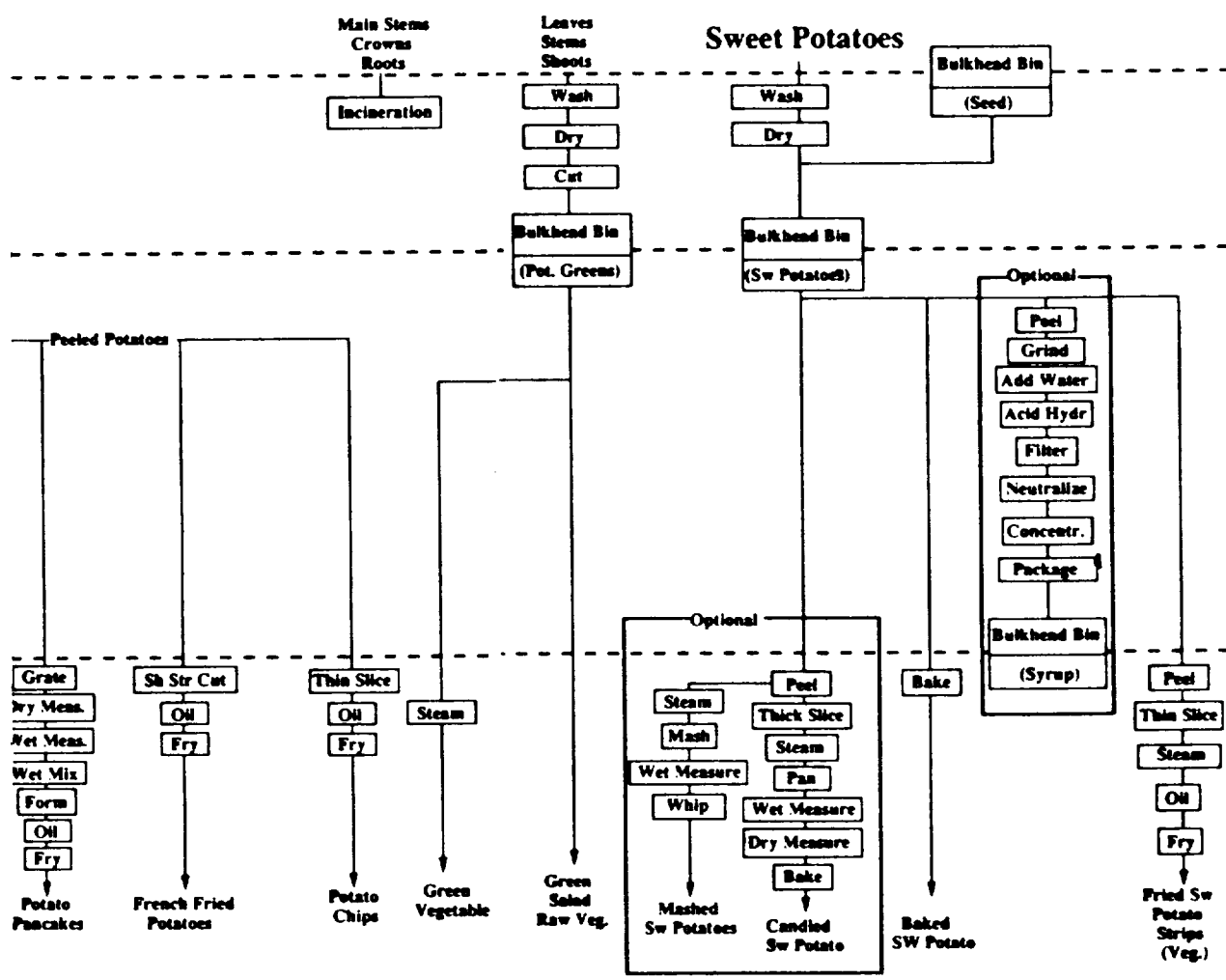


Figure 4

FOLDOUT FRAME

	BH	BI	BJ	
1				
2	PROCESS WORKSHEET			
3				
4	6	7	8	
5	Peel	Trim	Thresh.	
6				
7	Peel Chips	Cooked Soy Pods	Soy Milk	Too
8	Mashed Potatoes	Green Veg SW P	Soy Yogurt	Too
9	Potato Flour	Green Sal SW P	Soy Icecream	Pot
10	Potato Starch	Hors D' SW P	Tofu	Sal
11	Dextrose		Tempe	Gre
12	Potato Salad		Cooked Beans	Gre
13	Potato Puffs		Puffed Beans	Hor
14	Potato Pancakes		Soy Flour	
15	Hash Browns		Soy Sprouts	
16	French Fries		Wheat Berries	
17	Potato Chips		Simd Sprouts	
18	Sauted Potatoes		Salad	
19	Candied SW P		Bulgur Wheat	
20	SW Potato Flour		Simd Wheat	
21	Mashed SW P		Whi Flakes	
22	SW Potato Chips		Whi Flour	
23	Cooked SW Pot		Whi Gluten	
24	SW Potato Cake		Whi Starch	
25	SW Potato Puff		Bread Rolls	
26	SW Potato Syrup		Swi Bread etc	
27	Fried SW Potato		Dumplings	
28			Waffles/Pcakes	
29			Muffins	
30			Pasta	
31			Cereal	
32			Snacks	
33			Beverage	
34				
35				
36				
37				
38				

FOLDOUT F

[illegible]

NAME

2

BU	BV	BW	BX	BY	BZ	CA	CB	CC
			1					
			2					
			3					
20	21	22	4	24	25	26	27	28
Mill	Rasp	Homogenize	5	Steam	Bake	Fry	Saute	Blanch
			6					
uc Soy Milk	Potato Starch	Soy Milk	7	Soy Milk	Bread Rolls	Peel Chips	Sauteed Potatoes	
r Soy Yogurt	Dextrose	Soy Yogurt	8	Soy Yogurt	Swi Bread etc	Potato Pancake		
4 Soy Icecream		Soy Icecream	9	Soy Icecream	Waffles/Pcakes	Hash Browns		
s Tofu			10	Tofu	Muffins	French Fries		
Soy Flour			11	Tempe	Baked Potato	Potato Chips		
Wht Flour			12	Cooked Beans	Bkd SW Potato	SW Pot Chips		
Wht Gluten			13	Puffed Beans	Cand'd SW Pot	SW Pot Puff		
Wht Starch			14	Cooked Pods	SW Pot Cake	Fried SW Pot		
Bread Rolls			15	Soy Flour				
Swi Bread etc			16	Soy Sprouts				
Dumplings			17	Simd Sprouts				
Waffles/Pcakes			18	Bulgur Wheat				
Muffins			19	Simd Wheat				
Pasta			20	Wht Flakes				
Cereal			21	Dumplings				
Snacks			22	Mashed Potato				
Potato Flour			23	Potato Flour				
Potato Starch			24	Potato Salad				
Dextrose			25	Potato Puffs				
SW Pot Flour			26	Sauteed Potatoes				
			27	Green Veg				
			28	Cand'd SW Pot				
			29	SW Pot Flour				
			30	Msh'd SW Pot				
			31	SW Pot Chips				
			32	Cookd SW Pot				
			33	SW Pot Puff				
			34	Fried SW Pot				
			35					
			36					
			37					
			38					

FOLDOUT FRAME

3.

[illegible]

FOLDOUT FRAME

[illegible]

POLDOUT FRAM

[illegible]

IE 6.

DO	DP	DD	DR	DS		DT	DU	DV
					1			
					2			
					3			
69	70	71	72	73	4	74	75	76
Separations	Solids-Solids	Dehull	Chaff	Acidity	5			Manual Form
					6			
		Soy Milk	Simd Sprouts	Tempe	7			Potato Pancake
		Soy Yogurt	Salad		8			SW Pot Cake
		Soy Icecream	Bulgur Wheat		9			
		Tofu	Simd Wheat		10			
		Tempe	Whi Flakes		11			
		Cooked Beans	Whi Flour		12			
		Puffed Beans	Whi Gluten		13			
		Soy Flour	Whi Starch		14			
			Bread Rolls		15			
			Swi Bread etc.		16			
			Dumplings		17			
			Waffles/Pcakes		18			
			Muffins		19			
			Pasta		20			
			Cereal		21			
			Snacks		22			
			Beverage		23			
					24			
					25			
					26			
					27			
					28			
					29			
					30			
					31			
					32			
					33			
					34			
					35			
					36			
					37			
					38			

Figure 5

PRELIMINARY MENU

WEEK 1

MONDAY BREAKFAST	TUESDAY BREAKFAST	WEDNESDAY BREAKFAST	THURSDAY BREAKFAST	FRIDAY BREAKFAST	SATURDAY BREAKFAST	SUNDAY BREAKFAST
WAFFLES & SYRUP TOFU OMELET TOAST BEVERAGE	TOFU OMELET HASH BROWNS BISCUITS BEVERAGE	HOT/COLD CEREAL HOT MUFFINS BEVERAGE	PANCAKES & SYRUP COLD CEREAL BEVERAGE	GLUTEN SAUSAGE HASH BROWNS TOAST BEVERAGE	BAGELS & TOFU CREAM CHEESE HOT CEREAL BEVERAGE	FRENCH TOAST & SYRUP COLD CEREALS BEVERAGE
LUNCH	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH
CHEF SALAD POTATO AU GRATIN HOT ROLLS BEVERAGE	BAKED MACA- RONI & TOFU CHEESE GREEN SALAD VINAGRETTE FRESH BREAD BEVERAGE	GRILLED TOFU REFRIED BEANS STEAMED GREENS FLOUR TORTILLAS BEVERAGE	MIXED SPROUT SALAD BROILED TEMPE SERVED ON BULGUR FRESH BREAD BEVERAGE	TOFU OMELET FRENCH FRIES STIR FRY SOY PODS BEVERAGE CAKE	NOODLES ALFREDO GREEN SALAD VINAGRETTE FRESH ROLLS BEVERAGE	THICK POTATO SOUP FRESH BREAD BEVERAGE TOFU ICE CREAM
DINNER	DINNER	DINNER	DINNER	DINNER	DINNER	DINNER
BROILED TEMPE MASHED POTATO STIR FRY GREENS FRESH BREAD TOFU ICE CREAM BEVERAGE	GLUTEN & GREENS STIR FRY BAKED SW. POTATO HOT ROLLS COOKIES BEVERAGE	GRILLED TOFU CUTLETS SAUTEED POTATO STEAMED GREEN SOYBEANS TOSSED GREEN SALAD FRESH BREAD PUDDING BEVERAGE	THICK POTATO SOUP SALISBURY STEAK MASHED POTATO MIXED SPROUT & GREENS SALAD VINAGRETTE FRESH BREAD ASS'T'D COOKIES BEVERAGE	MEATLOAF POTATO SALAD STIR FRY MIXED GREENS HOT ROLLS TOFU ICE CREAM BEVERAGE	GRILLED GLUTEN SAUSAGES ON STEAMED, SAU- TEED BULGUR OVEN ROAST POTATOES STEAMED SOY PODS FRESH BREAD BEVERAGE	TEMPE & NOODLE CASSEROLE STEAMED SW. POTATO GREENS SAUTEED POTATO GREEN SALAD VINAGRETTE HOT ROLLS SWEET POTATO PIE BEVERAGE

Figure 6a

WEEK 2

MONDAY BREAKFAST	TUESDAY BREAKFAST	WEDNESDAY BREAKFAST	THURSDAY BREAKFAST	FRIDAY BREAKFAST	SATURDAY BREAKFAST	SUNDAY BREAKFAST
ENGLISH MUFFINS HOT/COLD CEREAL TOFU YOGURT BEVERAGE	PANCAKES & SYRUP TOFU SCRAM- BLED EGGS TOAST BEVERAGE	BAGELS & TOFU CREAM CHEESE GRILLED GLUTEN SAUSAGES BEVERAGE	GRILLED TOFU HASH BROWNS TOAST BEVERAGE	WAFFLES & SYRUP GRILLED SAUSAGES BEVERAGE	FRIED TEMPE & POTATO HASH TOAST BEVERAGE	ENGLISH MUFFINS HOT/COLD CEREALS BEVERAGE

LUNCH	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH
MIXED SPROUT SALAD STIR FRIED TEMPE AND GREENS FRENCH FRIES HOT ROLLS BEVERAGE	PASTA SALAD TOSSED GREENS VINAGRETTE HOT ROLLS COOKIES BEVERAGE	TEMPE MUSHROOM BURGERS FRENCH FRIES BEVERAGE	TABOULI SALAD GLUTEN SAUSAGES HOT ROLLS BEVERAGE	MEATBALLS & SPAGHETTI FRESH BREAD BEVERAGE	POTATO RISSOLE SWEET/SOUR SPROUTS POTATO PANCAKE HOT ROLLS BEVERAGE	LASAGNA WITH TEMPE & MUSH- ROOM SAUCE MIXED GREENS SALAD FRESH BREAD BEVERAGE

DINNER	DINNER	DINNER	DINNER	DINNER	DINNER	DINNER
PIZZA MIXED GREEN SALAD VINA- GRETTIE SWEET POTATO PIE BEVERAGE	MACARONI & CHEESE GRILLED TEMPE STEAMED SW. POT. GREENS FRESH BREAD TOFU ICE CREAM BEVERAGE	TOSSED GREEN SALAD TEMPE OVER NOODLES WITH MUSHROOM SAUCE MASHED SW. PO- TATO HOT ROLLS CAKE BEVERAGE	TOFU & TEMPE STEW WITH WH. & SW. POTATO STEAMED MIXED GREENS FRESH BREAD TOFU ICE CREAM BEVERAGE	MEATLOAF STEAMED & SAUTEED BUL- GUR AND MUSH- ROOMS MASHED SW. PO- TATO HOT ROLLS COOKIES BEVERAGE	BROILED TOFU CUTLETS HASH BROWNED POTATOES STIR FRIED GREENS FRESH BREAD CAKE BEVERAGE	GRILLED GLUTEN SAUSAGES OVER NOODLES WITH MUSHROOM SAUCE CANDIED SW. PO- TATOES STEAMED GREEN SOYBEANS COOKIES BEVERAGE

Figure 6b

WEEK 3

MONDAY BREAKFAST	TUESDAY BREAKFAST	WEDNESDAY BREAKFAST	THURSDAY BREAKFAST	FRIDAY BREAKFAST	SATURDAY BREAKFAST	SUNDAY BREAKFAST
BAGELS & TOFU CREAM CHEESE TOFU MUSH- ROOM OMELET BEVERAGE	HOT/COLD CEREALS ENGLISH MUFFINS BEVERAGE	PANCAKES & SYRUP GRILLED GLUTEN SAUSAGES BEVERAGE	HOT MUFFINS TOFU SCRAMBLED EGGS COLD CEREAL BEVERAGE	GRILLED TEMPE & POTATO HASH COLD CEREAL SWEET ROLLS BEVERAGE	WAFFLES & SYRUP TOFU OMELET BEVERAGE	ENGLISH MUF- FINS GRILLED SAUSAGE COLD CEREAL BEVERAGE

LUNCH	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH
TWICE BAKED AND STUFFED POTATOES WITH TOFU CHEESE SAUCE MIXED GREEN SALAD VINA- GRETTE MUFFINS BEVERAGE	SPAGHETTI & MEATBALLS STEAMED SW. POTATO GREENS FRESH BREAD BEVERAGE	TEMPE BURGERS FRENCH FRIES BEVERAGE	MACARONI & TOFU CHEES GRILLED TOFU CUTLET STEAMED SOY PODS AND GREEN SOYBEANS HOT ROLLS BEVERAGE	COLD PASTA SALAD WITH GREEN SOY- BEANS AND PODS. SAUTEED CUTS OF SW. POTATO FRESH BREAD BEVERAGE	PIZZA FRESH GREEN TOSSED SALAD BEVERAGE	MEATLOAF MASHED POTATO STIR FRIED MIXED GREENS HOT ROLLS BEVERAGE

DINNER	DINNER	DINNER	DINNER	DINNER	DINNER	DINNER
THICK SOUP WITH GNOCCHI SAUTEED TOFU A LA KING OVER NOODLES CANDIED SW. POTATOES STEAMED SW. POTATO GREENS FRESH BREAD CAKE BEVERAGE	BROILED TEMPE STEAMED BUL- GUR STIR FRIED MIXED GREENS FRESH BREAD TOFU ICE CREAM BEVERAGE	STIR FRIED GLUTEN STRIPS WITH GREENS AND POTATO DICES. HOT ROLLS SWEET POTATO PIE BEVERAGE	LASAGNE WITH TEMPE & MUSH- ROOMS TOSSED FRESH GREEN SALAD VINAGRETTE FRESH BREAD COOKIES BEVERAGE	GRILLED TEMPE POTATO PANCAKE STEAMED SW. POTATO GREENS HOT ROLLS TOFU ICE CREAM BEVERAGE	BAKED MUSH- ROOM, POTATO DICE, TEMPE & TOFU CASSEROLE STIR FRIED MIXED GREENS HOT ROLLS SWEET POTATO CAKE BEVERAGE	GLUTEN & GREENS STIR FRY BAKED SOYBEANS, BOSTON STYLE HOT ROLLS TOFU PUDDING & COOKIES BEVERAGE

Figure 6c

1. Slow Speed

Equipment in this category is usually grouped as mixers. Typical of the all-purpose types are the KitchenAid, K-Tec and Kenwood units and their equivalents.

2. Intermediate Speed

Typical of this genre are food processors. Cuisinart and its equivalents defined this type and, compared with mixers and blenders, are relative newcomers to the field of food preparation.

3. High Speed

Blenders define this category. Waring and Osterizer are typical of the type.

None of the multi-purpose equipment available spans all three regimes. But there is a considerable overlap in the functions of the attachments of each type, particularly of types 2 and 3, and principally in slicing operations. The mixers (type 1) tend to use cylindrical cutters while the food processors use radial, plate or blade cutters at much higher speed.

For the purpose of simplicity, one type would be preferable for a space station. However, at the outset of the study, it was not clear that any one type offered compelling advantages or that it could be adapted to cover all three types. Each was therefore evaluated independently, and the "best" design developed for particular operations. Some are type 2 based, some type 1. In the investigation of these various equipments, the project team has tried to take into consideration other important factors such as weight, cube, ease of assembly and use, and ease of cleaning.

What follows is an evaluation of what was commercially available, why it was selected, how it was adapted, and what the results were. Where nothing was available, the designs and prototypes developed are described, with recommendations for future development if deemed necessary.

The following pages present listings of equipment estimated needed to satisfy the unit operations requirements identified above, and notations as to whether; suitable equipment is commercially available, available but needing modification to be suitable for zero-gravity operation, or suitable equipment is not available and concept designs are required. To avoid misunderstanding, it is assumed by the research team, that virtually all of the equipment aboard a CELSS has been especially designed and constructed. The notation regarding modification in this figure refers to whether the team felt the equipment available could function suitably in a zero gravity environment.

MATERIALS HANDLING/PARTICLE CONTROL

The tables address food and biomass processing equipment. Not

included is equipment used in the more general operations of material handling, such as conveying and metering. By virtue of daily harvest/daily planting, the quantities being handled have minimized the potential problems involved in materials handling. By the same token, they also minimize the feasibility of automating processes.

The major concern about materials handling procedures/conveying related to particle control. In a zero-gravity environment, in close proximity to highly sensitive instruments, absolute particle control is essential. To help achieve that, virtually all conveying would be done by aspiration to ensure that any leaks would be inward, not outward. Handling of fine particulate materials would be done with vacuum wands or, as in the case of trayng biomass and other particulates, in a vacuum tray table in a glove box.

IDENTIFICATION/DISCUSSION OF COMMERCIALY AVAILABLE EQUIPMENT SUITABLE FOR CELSS APPLICATION "AS IS", OR WITH SLIGHT MODIFICATION

Few pieces of existing commercially available food processing equipment are suitable, "as is" for zero-gravity, however, many units can be made suitable with comparatively minor modification. It is assumed that virtually all this equipment would require at least some redesign to be compatible with CELSS systems and stowage requirements, as well as to provide the throughput. Figure 7 below provides a listing of commercially available equipment felt suitable for CELSS under zero-gravity conditions, possible suppliers, and an indication of whether operational modification(s) are necessary. The identification of manufacturers does not constitute an endorsement, or an opinion as to the quality of the unit cited relative to its competitors, but to validate the data, and provide NASA a point of contact for verification.

This is an extremely dynamic segment of the foods industry in which equipment development is very aggressively pursued. In all cases, an equivalent or superior unit could be substituted.

Figure 7. - EQUIPMENT REQUIREMENT OF CELSS UNIT OPERATIONS

<u>UNIT OPERATION</u>	<u>PRODUCT/USE</u>	<u>EQUIPMENT</u>	<u>TYPICAL MANUFACT'R</u>	<u>MODIFY</u>
Homogenization	liquids	homogenizer	Armfield	N
Chill/Heat	beverages	heat exchanger	MidWest Res.	Y
Freeze (liquids)	desserts	heat exchanger	Waring/Oster	Y
Bake-griddle	waffles	griddle	Toastwell	Y
Mill	flour	mill	K-Tec	Y
Mix	dry ingreds	spice mill	Braun	Y
Dehull	soybeans	plate mill	Quaker	Y
Measure	liquids	syringe	-	N
Slice/grate	vegetables	slicer/grater	K-Tec	Y
Shoestring cut	vegetables	shoestring cut'r	K-Tec	Y
Flake/crack	grain/beans	flaking mill	-	Y
Grind/chop/mince	vegetables	grinder	K-Tec	Y
Extrude	pasta/snacks	extruder	K-Tec	Y
Dehydrate	vegetables	dehydrator	Amer. Harv.	Y

Pasta press	pizza	man. press	-	Y
Bake/fry/stir fry	veg./bak. gds	high vel. oven	Amer. Harv.	Y
Puff	snacks	microwave oven	-	Y
Toast/roast	bread/grain	high vel. oven	Amer. Harv.	Y
Proof/sprout	bak.gd/grain	cont. temp. oven	-	Y
Chop	biomass	food processor	Cuisinart	Y
Mill	biomass	mill	K-Tec/Glen	Y

DISCUSSION OF EXISTING, AVAILABLE EQUIPMENT

HOMOGENIZER

Within the process flows shown in Figures 3a, b, c, d, and 4, homogenization is required only in the production of soy-milk, which is, in turn, used as a beverage, as well as the chief ingredient in tofu, yogurt, and frozen yogurt. Although soybeans are also used for sprouts and tempe, it would be prudent to assume that tempe and sprouts will not be prepared every day, and that at times, the entire soybean production could go in to the production of soymilk, and its products, including; tofu, and yogurt. Based on this scenario, we could need to be able to homogenize approximately 33 L per day. To avoid having this operation constitute a bottleneck, it would be desirable to have a throughput capacity on the order of 30L/hr. Because of the pressures involved in homogenization, these units are usually heavy and have high horsepower requirement. Soymilk requires only modest pressures, i.e., 210Kg/cm². Though two-stage units are commonly used, single stage units may be sufficient. Other manufacturers with higher pressure capability than Armfield include: Manton-Gaulin, Microfluidics, and their equivalents.

CHILLER/HEATER

Chilling/heating are essential to achieving good acceptance, particularly in the case of beverages. In this case, the electric heater/cooler should be able to heat beverages as high as 155° C, or cool them to approximately 3°C, under normal conditions. The MidWest unit was developed in conjunction with Natick Laboratories for use by crews of tanks and other combat vehicles. The advantage of this design is that electrical energy is used directly to accomplish the cooling without the need for intermediate refrigerants and/or heat exchangers.

FREEZER (LIQUIDS)

The purpose of this unit is to provide astronaut crews with frozen yogurts and other frozen desserts. The technology is similar to the home ice cream freezer except that the crushed ice and rock salt are replaced by a refreezable heat transfer medium contained in the jacket of the unit, and the cranking is performed by a small electric drive. Preliminary tests of one of these units showed it performed well with reconstituted soymilk. Freezing was complete but soft within 25 minutes. Additional freezing would be desirable for hardening prior to consumption. It is suggested that some product development be

devoted to soy-based frozen desserts. Particularly in the areas of flavorings and stabilizers. In operation, it is anticipated that the materials would be transferred to the freezer with a syringe. After freezing, the materials are sufficiently sticky and cohesive that an ordinary ice cream scoop should work very adequately, even in zero-gravity.

GRIDDLE (WAFFLES)

The advantage of the griddle for CELSS operations is its potential product versatility because of plate changes, the flavor development that accompanies this form of cooking, and the fact that the unit is usually closed during the cooking process, preventing escape of particles and volatiles. Products prepared on this unit might include; tofu, tempe, waffles and potato pancakes. In screening specific units, it is recommended that basic requirements include the ability to change plates easily and quickly. In making waffles, a syringe would be used to transfer batter into the unit. Tongs would suffice to remove cooked waffles. It is anticipated that in a zero-gravity environment, waffles would not be eaten on a plate with margarine and syrup, but more in the manner of toast with added spreads.

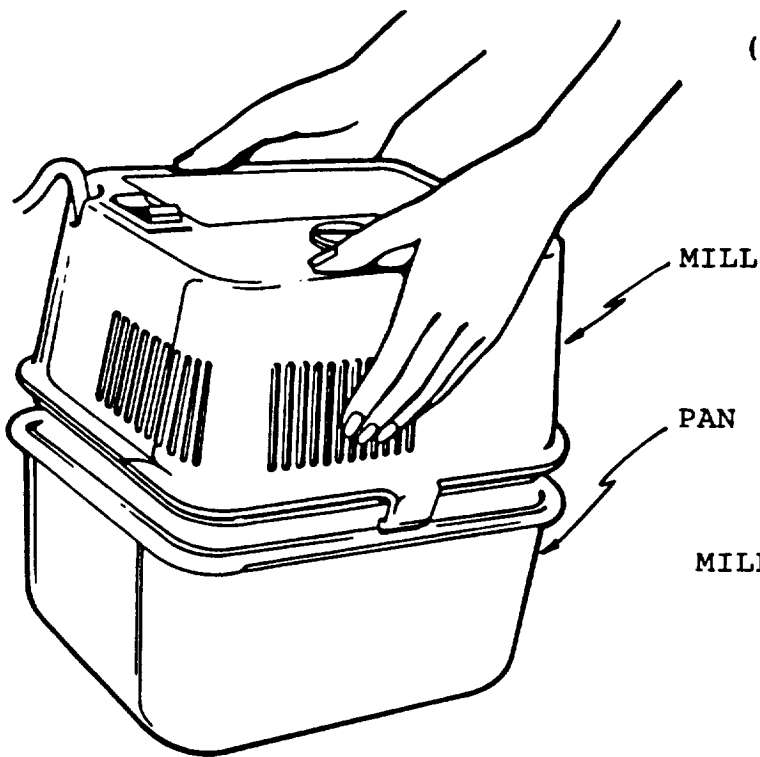
MILL (FLOUR)

A large number mills exist for milling flour from wheat and other grains. These include stone mills, burr mills, and plate mills. Most would suffice if it were not desirable to be able to mill soybeans. Oily materials do not work well in most of these units, and many non-stone units, including the KitchenAid milling attachment, do not mill sufficiently fine for some of the baked goods that would be desirable for long term CELSS missions.

In concept, wheat heads received from harvest would be dried sufficiently for threshing, threshed, separated (wheatberries from chaff), with the wheatberries milled to flour, and aspirated to a bulkhead bin in the PROCESSING AREA in essentially an automated procedure. Some intervention may be required if it is desired to retrieve berries for sprouting prior to milling.

The K-Tec mill and its equivalents, because of their use of impact/shear action as contrasted with abrasion and crushing, is capable of handling soybeans as well as grains. The K-Tec unit performed well in a test in which wheatberries were aspirated into the mill, milled into a fine flour which was aspirated into a receiving canister built into a cyclone. The results of these tests were acceptable in that the flour was very fine and suitable for both bread and sweet doughs. For additional insurance in particle control, however, it is suggested that provision be made to increase air flow through the mill head. Discussion with engineers indicate this change could be accomplished easily. Figures 8 and 9 respectively show the

K-TEC MILL AND RECIEVER PAN BASE
(PAN NOT NEEDED IN ZERO-GRAVITY)



MILL SHOWING INFEED
(ZERO-GRAVITY WOULD
REQUIRE HOUSINGS
AND ASPIRATION
TO CARRY GRAIN
INTO THE MILL)

MILLING ADJUSTMENT

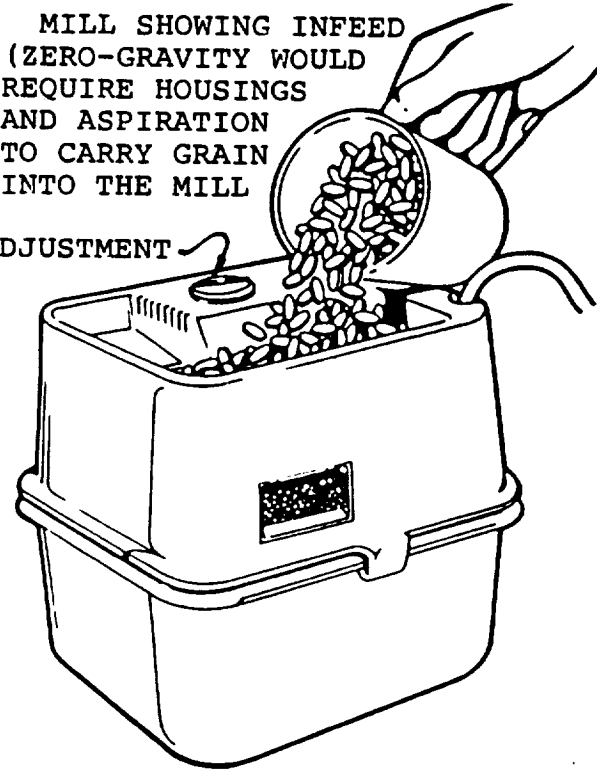
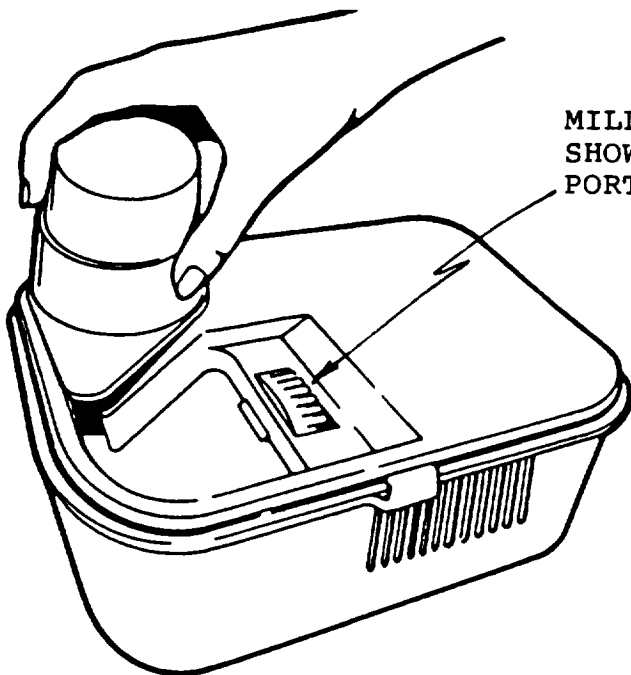


Fig. 8 is a page copied from
the manufacturer's technical
bulletin.



MILL INVERTED.
SHOWING DISCHARGE
PORT

The K-TEC Kitchen Mill

The Kitchen Mill Will Mill the Following: *

Wheat (hard & soft)
Dried pinto beans
Dried green peas
Dried sweet corn
Sorgum (milo)
Buckwheat
Triticale
Popcorn
Barley
Millet
Oats
Rice
Rye

Dried beans (most types)
Dried garbanzo beans
Legumes in general
Dried pinto beans
Dried mung beans
Feed/Field corn
Dried lentils
Oyster shells
Bee pollen
Split Peas
Chickpeas
Soybeans

Figure 8

* - Manufacturer's claim, not verified
by Food and AgroSystems

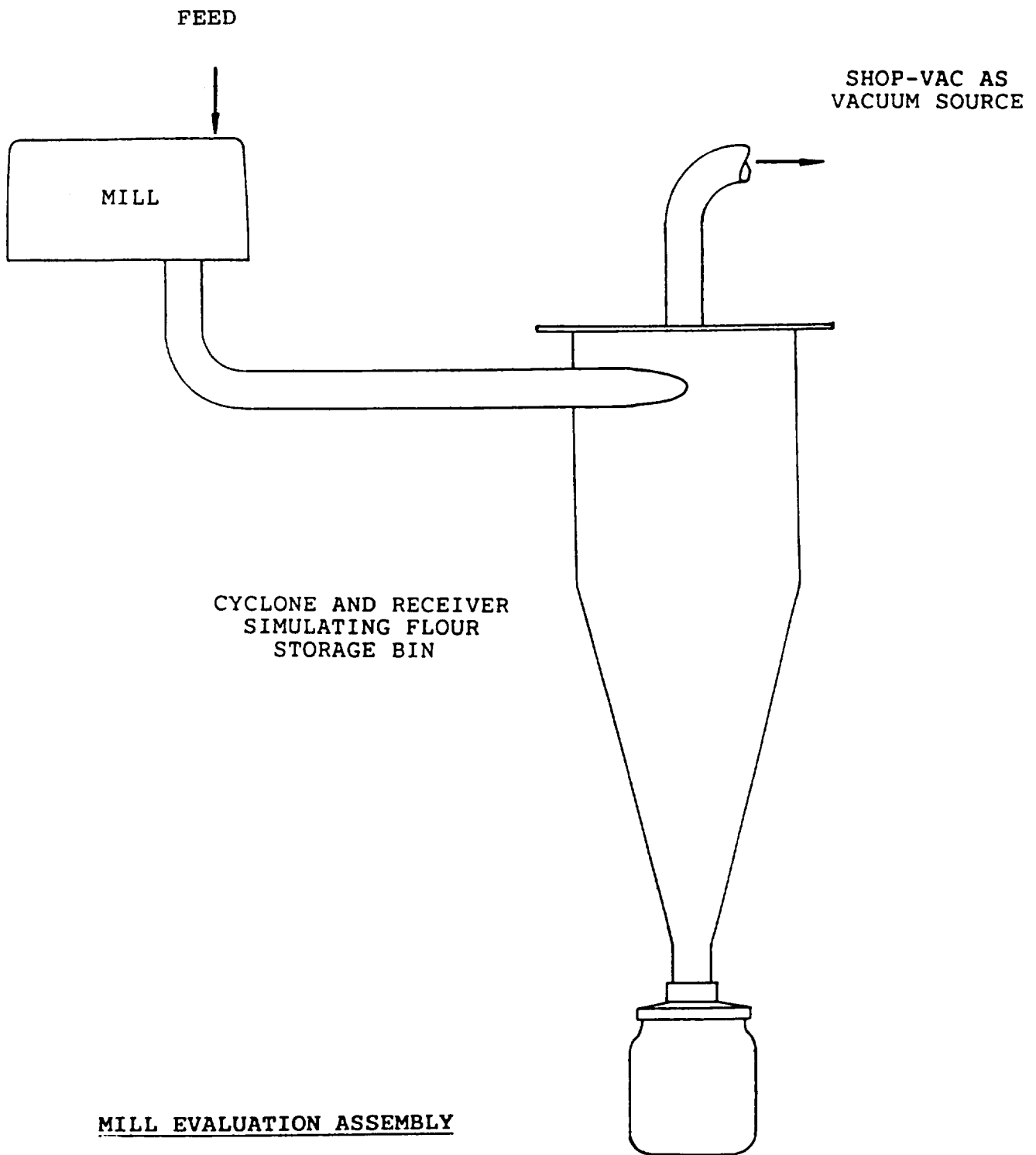


Figure 9

general configuration of the mill and the and the system used for the prototype evaluation.

In designing an integrated, automated milling system, provision will be needed to cope with the static charges developed.

MIXER (DRY INGREDIENTS)

Major considerations in mixing systems for dry particulates include; particle size, particle size uniformity, and particle fragility. In the case of zero-gravity, the importance of density disappears, but the importance of inertia and static charges increase. Most mixing systems used commercially, such as, ribbon mixers, etc., use gravity as a factor in their design. With in the scope of unit operations used in the flow diagrams shown as Figures 3a, b, c, and 4, most mixing could be combined with a degree of milling action without adverse effects.

The advantage of this approach is the possible use of mixers configured similar to the small spice and coffee mills manufactured by Braun, Moulinex, and their equivalents. These units have a small spindle operating at very high speed in an smooth, rounded enclosure. The combination of these features results in the creation of strong air current which carry the particles around the inside of the chamber and through the cutters at high speed. In the case of the spice and coffee mills, the emphasis is on milling, with the air flow/mixing being important but still secondary to the cutting/milling. What would be desired is an enlarged version in which the blades would be configured more for air flow and circulation and less for cutting/milling. The majority of the operations requiring mixing of small dry particulates involve spices and comparatively small amounts. It is estimated that a unit with a capacity of approximately 1-2 L should be sufficient. A food processor proved effective for this application.

Mixing of larger dry particles which would be harmed by impact, such as vegetable mixtures in which it is desirable to maintain large size and particle identity, and operations such as oiling french fries or inoculating biomass would be handled differently. In these cases, the approach would depend largely on batch-size. In the case of crew sizes of 12 or less it is suggested that the mixer might be a manual system in which the particles would be collected in a flexible container such as a reuseable plastic bag. For operations in which the mixing involves addition of small amounts of sauces, dressings, oil, or even inoculating organisms, this approach is particularly advantageous since the amount of air space is minimized, the particles are not impacted or damaged, and the interaction of the particles aids in the distribution. In the case of french fries and most vegetable particles, the collection bag would be mounted at the discharge of the cutting devices.

DEHULL (SOYBEANS)

A number of devices available on the market appear to be able

to dehull soybeans effectively. Tests conducted on a plate-mill made by Quaker demonstrated essentially 100 percent cracking. The key in this operation is to split the beans and dislodge the hulls with a minimum of damage. When the cotyledons are damaged, lipoxygenase is liberated. This enzyme is extremely active and catalyzes the very rapid rancidification of the soy oils. With proper adjustment of plate mill clearance beans can be split with very little damage. In the trials conducted by FASI on commercially available dry soybeans, 0.4 cm clearance appeared satisfactory.

As in the case of milling, it would be highly desirable to have positive air flow through the unit to act as a conveying agent. Plate mills and similar units considered lend themselves well to adequate air flows. Separation of hulls from cotyledons can be achieved in a Mass-Inertia Separator described later in the report.

SLICE/GRATE

Several units were evaluated, including both powered models, such as the KitchenAid, Cuisinart, and K-Tec units, and manual units such as the classic mandolin design. The choice of unit is, to a degree, a factor of crew size. Below 6 crew, a mandolin unit might be the best choice. Above that, the powered models appear desirable.

KITCHENAID/K-TEC TYPE

The slicer/grater equipment is usually an attachment to what is essentially a drive unit capable of many applications. The slicer/grater attachment consists of a housing into which various conical cutters representing different cutting patterns can be inserted. The cutters are driven from a second power take-off that is faster than the mixer head. Within the context of a CELSS, the cutting assembly may be somewhat cumbersome and difficult to clean. The power of the equipment varies considerably. KitchenAid is in the range of 300 watts; K-Tec, which has almost identical but seemingly sharper cutters, weighs less than half the weight of the KitchenAid but is 1,300 watts, considerably higher than what would be necessary for slicing or grating. Both KitchenAid and K-Tec, and their equivalents, would require modest redesign to provide transport of the cut material into a receiving container under zero gravity. Air flow would appear to be the most feasible approach.

CUISINART-TYPE

The Cuisinart-type units have an advantage over the Kitchen Aid/K-Tec types in that it is unnecessary to attach a secondary piece of equipment; one simply changes the cutter. Furthermore, the cutter is about four times faster and the equipment is much easier to clean and store. Also, slices and gratings are collected in the standard bowl as they leave the cutter blade, whereas, in the Kitchen Aid/K-Tec types of units, they would have to be collected by aspiration.

The power of Cuisinart units is about 650 watts, more than adequate even for high-speed slicing.

Between KitchenAid and K-Tec, K-Tec offered much more power and a greater variety of cutter heads which, for CELSS application, could enable greater versatility. Both of the units suffered from a common problem in that significant amounts of vegetable tissue can become lodged between the cutter head and its housing during slicing/grating operation. FASI is currently working on a design to minimize this tendency.

A design improvement that should be added to all powered units would be a longer feed tube with a positive feed feature to reduce the personnel requirement.

FRENCH FRY CUTTER/DICER

Both powered and manual shoestring cutters were evaluated during the course of this investigation. An important factor in the choice is the number of potatoes that would need to be cut. Based on an estimated 5855 gms of potatoes per day for a crew of 12, and an estimated average weight of 300 gms, there would be about 19 to 20 potatoes per day that could be cut in some way. A 300 gm potato provides approximately 1 serving of fries. It is estimated that any single meal would require no more than 12 potatoes. Powered units, such as the Hobart attachment on the KitchenAid drive, were capable of cutting fries about 1 cm X 1 cm cross-section, but seemed too heavy and cumbersome in a CELSS application to be justifiable for 12 potatoes.

Cuisinart and Kenwood-type units have cutter blades fitting their food processors capable of cutting fries. The Cuisinart-type unit worked satisfactorily in laboratory tests.

Trials of cutter assemblies for producing rectangular or square cross-section fries indicated that pressures required to push potatoes through the cutter ranged as high as about 90 kg. This was estimated to be acceptable for lever actuated designs, but excessive for small manual units. Brief partial cooking in a microwave prior to cutting reduced the force required by about 70 percent, but this may not be acceptable for all products. In the case of manual cutters, the wedge cutter design commonly used for apples appears the most feasible. The 12 wedge cut provides fries at about the limit for crispness. One modification that would be highly desirable to all the powered units is the lengthening of the feed tube and the incorporation of a positive feed feature to reduce personnel requirement.

A commercial-type french fry cutter attachment was evaluated to determine whether it might be the basis for a lightweight space design. The answer is probably not, primarily because of its weight and cube, and the complexity of its fry-cutting attachment. The fry cutter works on a simple, brute force basis of driving a potato through a grid of cutting blades normal to the

direction of thrust. The cutter consists of two 10 cm square frames one behind the other and each with a grid of blades of 2 cm square. One grid is offset in a diagonal direction from the other so that the combined grid from a frontal perspective is a composite grid of 1 cm squares.

The feeder is a power-driven ram that forces a potato along a chute into the cutter grid. The ram is mechanically powered. A manually-engaged follower slots into a continuously revolving screw that drives the ram to the end of its stroke corresponding to the end of the screw flight. The ram can then be disengaged and manually shifted back to its starting position. Another potato is inserted and the cycle repeated.

An attempt was made to estimate the force required to drive a potato through the cutter assembly. As with previous tests, it was difficult to gauge dynamic force. In this case it was even difficult to measure initial force, because the full weight of a person was insufficient to push the potato through the grid. An estimate of the actual force necessary is between 90 and 100 kg for a large 13 cm x 7 cm x 6 cm potato. Compare this with 11 kg to force a potato about two thirds this size through the Cuisinart type (5 blade) throat and 36 kg to force a similar potato through the modified 7-blade Kitchen Aid-type slicer/dicer throat described later in this report (Figure 11).

Before it moves, the potato distorts significantly to a point where the back of the potato in contact with the pusher is actually crushed. Large commercial operations avoid this disadvantage by using water to propel the potatoes hydraulically through a grid. The water serves a double purpose of also cleaning the slices and washing away free starch.

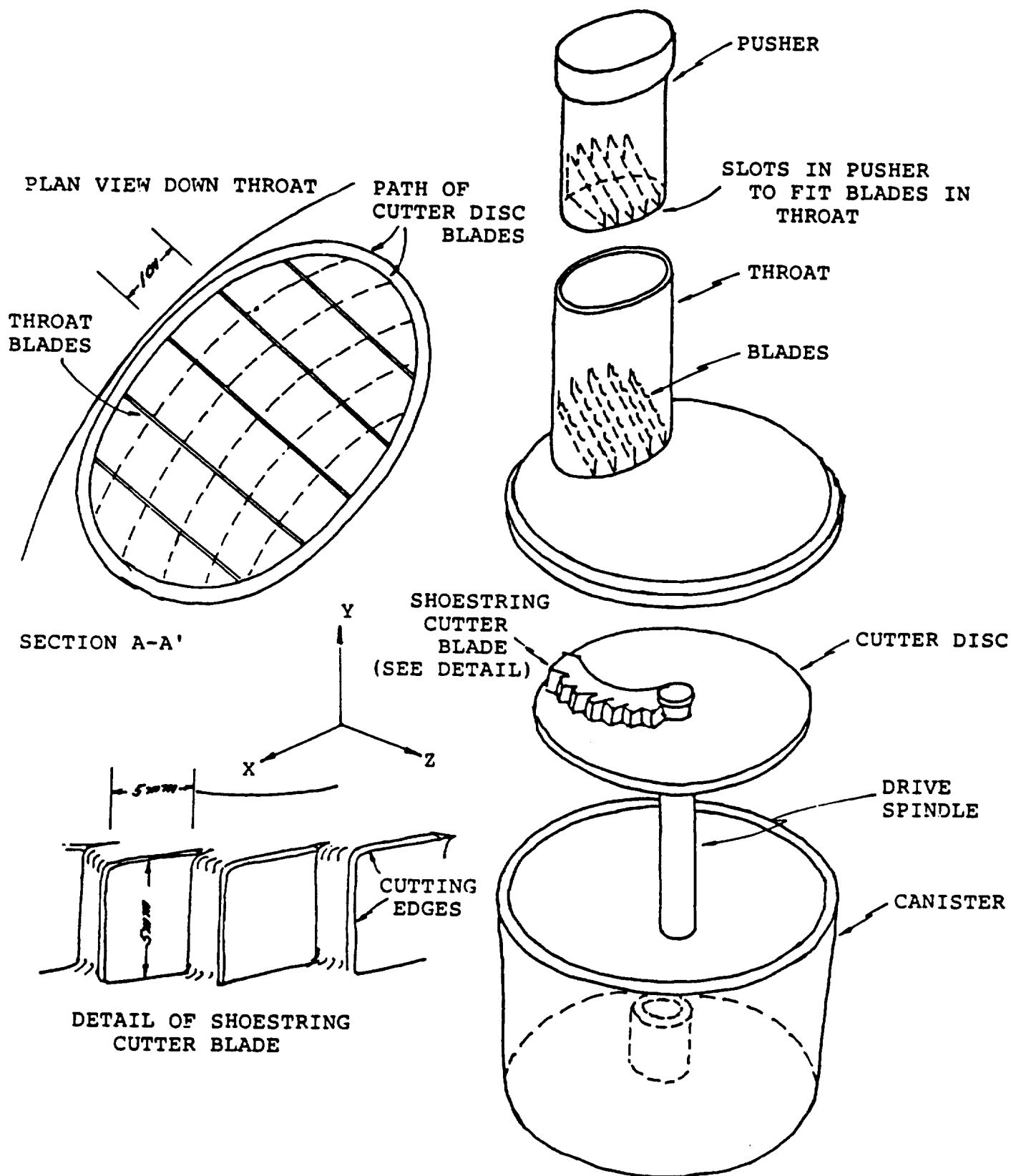
Our conclusion is that neither of these systems is appropriate for the scale of CELSS covered by this project.

CUISINART/DITO DEAN DISC-TYPE CUTTERS

Figure 10 shows a dicer, a prototype of which was made and successfully tested. It is essentially a modified Cuisinart food processor component. The system uses the standard motor base, bowl and a french fry cutter which, in unmodified form, simultaneously slices whole potatoes in two planes to make potato fingers for deep frying.

The modified section is the bowl top and pusher. The throat of the bowl top incorporates blades to cut in the third plane. Unlike the cuts in the other two planes which are power cuts, the third plane cut is manually accomplished. This is done by forcing a potato with an adapted pusher through the throat onto the rotating cutter.

Not much force is actually necessary to force the potato through the throat. There are two reasons for this. Firstly, the blades are relatively thin and very sharp. Secondly, the blades are inclined at about 45° to the direc-



CUISINART SLICER/SHOESTRING CUTTER
MODIFIED TO MAKE DICES

Figure 10

tion of thrust to introduce a large shear component. This makes the cut a slicing action rather than a parting action, and requires less force.

In the prototype, the blades were mounted in the throat by first cutting slots in the appropriate places and the cementing the blade in position with epoxy. When the epoxy had hardened, exposed sharp edges were ground off. The pusher was made of wood shaped to fit the throat and with an end to limit the pusher travel glued to it. Slots were sawed to provide clearance for the blades.

One drawback with the modified top is that it is difficult to position the pusher. Normally, the pusher would be able to just slide into the mouth of the throat behind even a large potato. Because the blades occupy much of the throat, the potato sticks out, and the pusher has to be carefully aligned to ensure that it can be pressed home in one smooth action. The cutting blade rotates very fast, and the potato must be pushed down onto the disc surface to present a surface to the blades before the next revolution. A ten centimeter-long potato is usually sliced in less than a second, so that if the pusher has to be realigned to press it home, potato puree is a more likely product than dices. A remedy is relatively straightforward. It would be simply to extend the feed tube and pusher by another eight to ten centimeters. The way the dices were actually produced was to slide the potato into the throat until it rested against the blades, switch on the cutter, then push the potato through the fixed blades.

Another consideration is the dimensions and shape of the dices. Because the cuts in the XZ plane are made with a circular motion, the dices produced at the major axis of the elliptical mouth tend to be rhomboidal in shape; those produced at the minor axis tend to be more nearly cubic. This is not considered to be an impediment to good cuisine. Also, because the standard french fry cutter was designed to make small fries of about half a centimeter square, the dices were rectilinear rather than cubic because the blade spacing in the throat was about one centimeter, closer to ideal. Notwithstanding these apparent drawbacks, the dices produced were very acceptable and produced with astonishing speed -- less than a second for a large potato.

Restaurant french fries are usually made from peeled potatoes. The dices produced were not. Removing the skins does not significantly change the cooking characteristics, nor does it impair the flavor. Some might argue that leaving the skins improves it. There is also a considerable reduction in waste and in preparation time. The only thing necessary was to trim particularly large potatoes so that they fit within the elliptical cross section of the feeder tube. Since larger machines are available with larger feed tubes, even this might be unnecessary.

The operation could be automated, but there should be a trade-

off between the time and tediousness of manually dicing (which for this operation is minimal) against the additional components and reliability of a fully automated system. Typically, one large, ten centimeter, potato would make the equivalent of a fast-food large fries helping. Therefore to feed ten astronauts, allowing time to trim, arrange and insert potatoes in the mouth would take a minute and a half to two minutes.

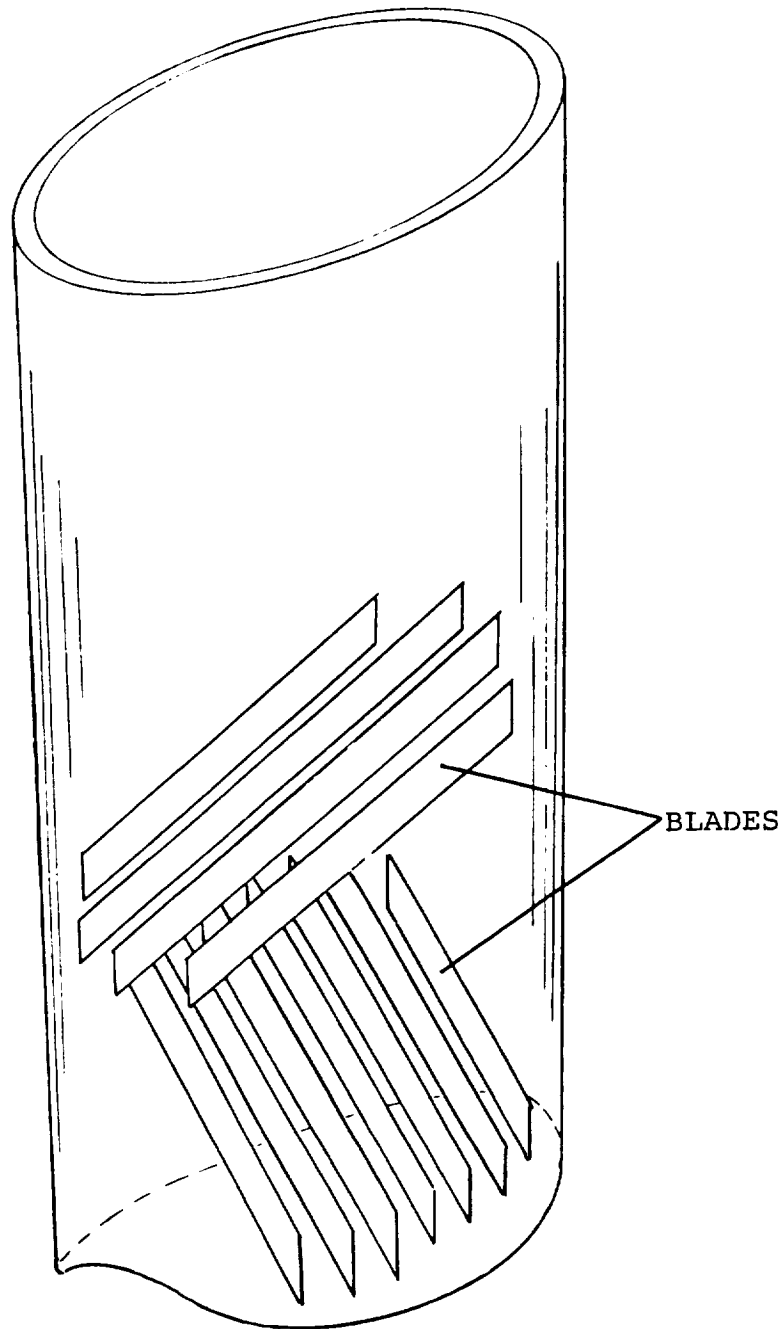
K-TEC-TYPE UNITS

As discussed in the section on slicing/grating, the K-Tec-type units use conical cutting heads similar in design to those of the KitchenAid-types, but with a greater variety of cuts, one of the cutters claimed to produce french fries. Tests with this cutter showed many irregular cuts, and few of the square/rectangular cross-section cuts normally associated with fries. Based on examination of this cutting head, it appears the problem results from trying to cram too many blades on the cutter head. Where there should be two or at the most three, the manufacturer has crammed six, with the result that a second blade is cutting into the product before the first blade has finished its cut. As a result, the cross-section shape of many of the "fries" resembled an inverted "v", with a much higher surface to volume ratio than normal fries. A test of these cuts in making fries showed them to be much more crisp than a standard fry, with flavor about half-way between potato chips and fries. Because of the accelerated crisping, this shape could have certain advantages.

KITCHENAID-TYPE FRENCH FRY CUTTER

Figure 11 shows a french fry cutter that was developed for KitchenAid-type units. Because installing blades in the feeder throat of a Cuisinart top had worked satisfactorily, it was assumed that adding blade in another plane would not make much difference. This turned out not to be the case. Friction appears to rise exponentially with the number of blades. Also, the spacing of the blades was diminished to make thinner sections, necessitating more blades. Another factor was that blades spanning the major axis of the throat were too long to be rigid. Any slight misalignment causes the blades to be deflected and bow in operation.

One reason this configuration would be preferred over the Cuisinart-type configuration for CELSS operation is that the fries would be cut along the major axis of a potato making them desirably longer in appearance, and making fewer small pieces. (The length of fries cut with the Cuisinart-type adaption is governed by the major axis of the feeder tube, 8 cm, i.e. the breadth, rather than the length of a potato.) However, because of the high frictional forces inherent in the design of the two banks of blades at 90° to each other, other blade configurations were considered.



MODIFIED DICING AND SHOESTRING CUTTING THROAT
FOR KITCHENAID SLICER/GRATER

Figure 11

WEDGE CUTTER (MANUAL)

Wedge cuts are becoming increasingly more common in french production. Apart from providing a more attractive way of presenting unpeeled potatoes, this approach has an important advantage from a purely mechanical standpoint. Figure 11a shows a standard manual apple corer which produces a pattern of twelve wedge cuts. Pushing this device through a raw potato of the type and size tested on the KitchenAid cutter assembly required approximately 11 kg as contrasted with the about 100 Kg for the KitchenAid. The difference is related to many factors including blade thickness, but the principal factor would appear to be the fact that in the wedge cutter design, the wedges can back out of the wedge as they are cut, markedly reducing the compression and frictional forces. Unless there is a commanding reason to remain with the traditional square or rectangular fry cross-sectional pattern, it would appear desirable to consider using the wedge pattern of cut.

MANDOLIN (MANUAL)

A traditional slicer and later french fry cutter for kitchen use has been a mandolin, a device with an inclined cutter on a washboard-like surface. In a CELSS application, this could pose a danger to crew due to the possibility of cuts. A typical mandolyn unit is made by Boerner of Germany, the principal features of which are shown in Figure 12.

From our observations, three things are important in a fry cutter:

1. It must have very thin blades. Potatoes are relatively incompressible, and it is almost impossible to force a potato through a straight grid without crushing the potato unless the blades are very thin, regardless of how sharp they are. The mandolyn blades are a mere 0.2 mm thick compared with the 0.33 mm of the cutter knife blades used to make the test Cuisinart-type dicer and the KitchenAid-type slicer/dicer. The hacksaw blades used in the unit that will be described are nearly three times as thick at 0.56 mm. The throats of the modified Cuisinart and the Kitchen Aid type slicer/dicer are almost identical, with 8 cm x 5 cm elliptical areas. The former has 5 inclined blades in the throat, the latter 7. However, the static force to slice a potato is three times greater for the 7-blade throat (about 35 kg). We can only conclude that the extra pinching required to have the potato slices pass the blade drive up the reaction to the plane of the blades and the resulting friction force exponentially.
2. The blades must be staggered. To avoid the pinching inherent in a flat grid, a piece being cut from a potato must be free to move to one side of a blade as it is parted. This means that any section of the potato should be completely clear of one blade before encountering another.

Potato Wedge Cutter

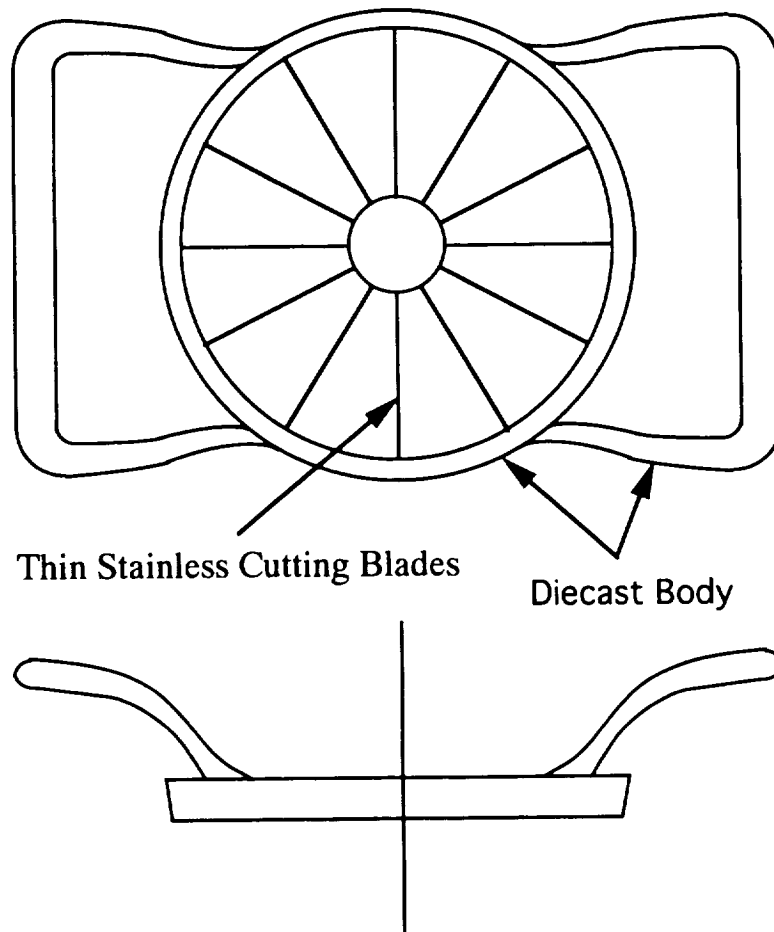
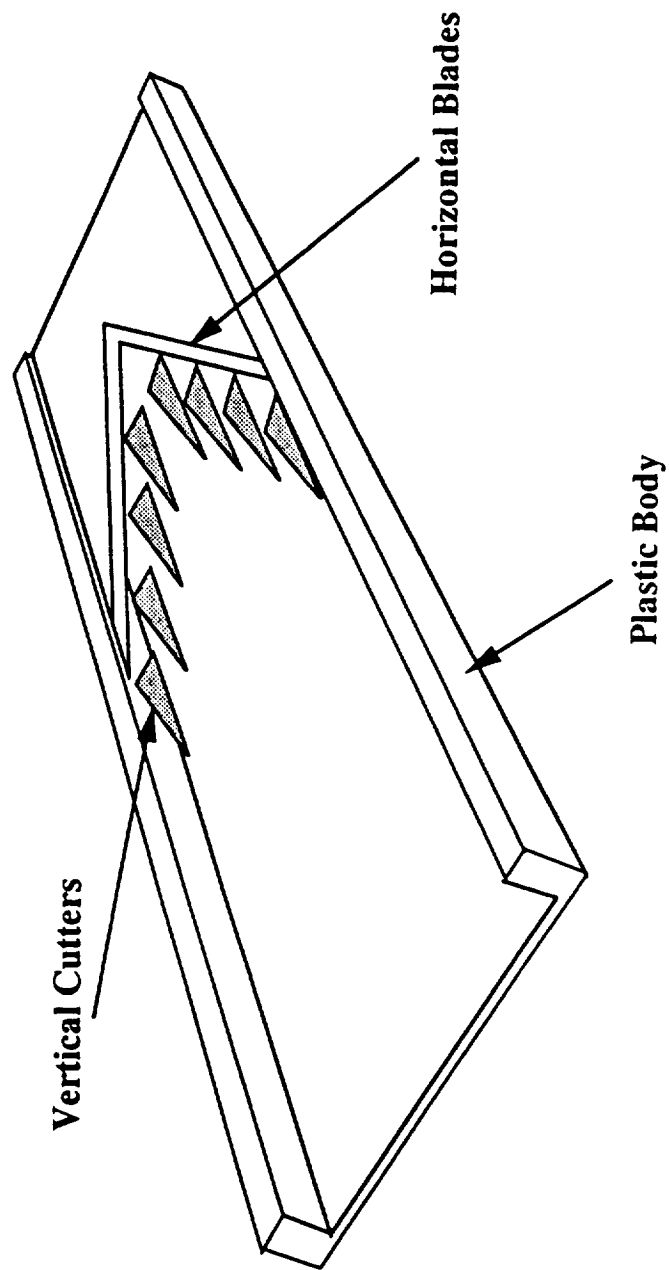


Figure 11a



Boerner French Fry Cutter

Figure 12

3. The blades should be raked. At 30° , the angle on the mandolyn is much more acute than traditional designs, and is made in a "V" which not only centers a potato but also avoids the need to make the mandolin too long.

Figure 13 shows the unit that evolved, the Blue Angel design. Hack saw blades were selected as the toughest easily available material suitable to span the 8 cm axis with a 30° rake. They were sharpened, but still had a ragged edge from the tooth profile to provide a breadknife-type cutting edge.

Because two sets of blades at 90° had not proved satisfactory, it was assumed that blades thicker than those tried before had a minimal chance of success even if the rake angle were much greater, and even if the blades were staggered. Thin, stainless blades needed to be attached to the hacksaw blades to resemble the layout of the Boerner-type mandolin. To balance the loads, a delta profile was selected in a staggered arrangement. The cross blade thickness was 0.4 mm.

These cross blades were attached by notching the hacksaw blade at its leading edge and spot welding them at the trailing edge. In this way, the critical sharp edge of the hacksaw blade would not lose its temper. A pusher was constructed of redwood, slotted in two planes to clear the blades.

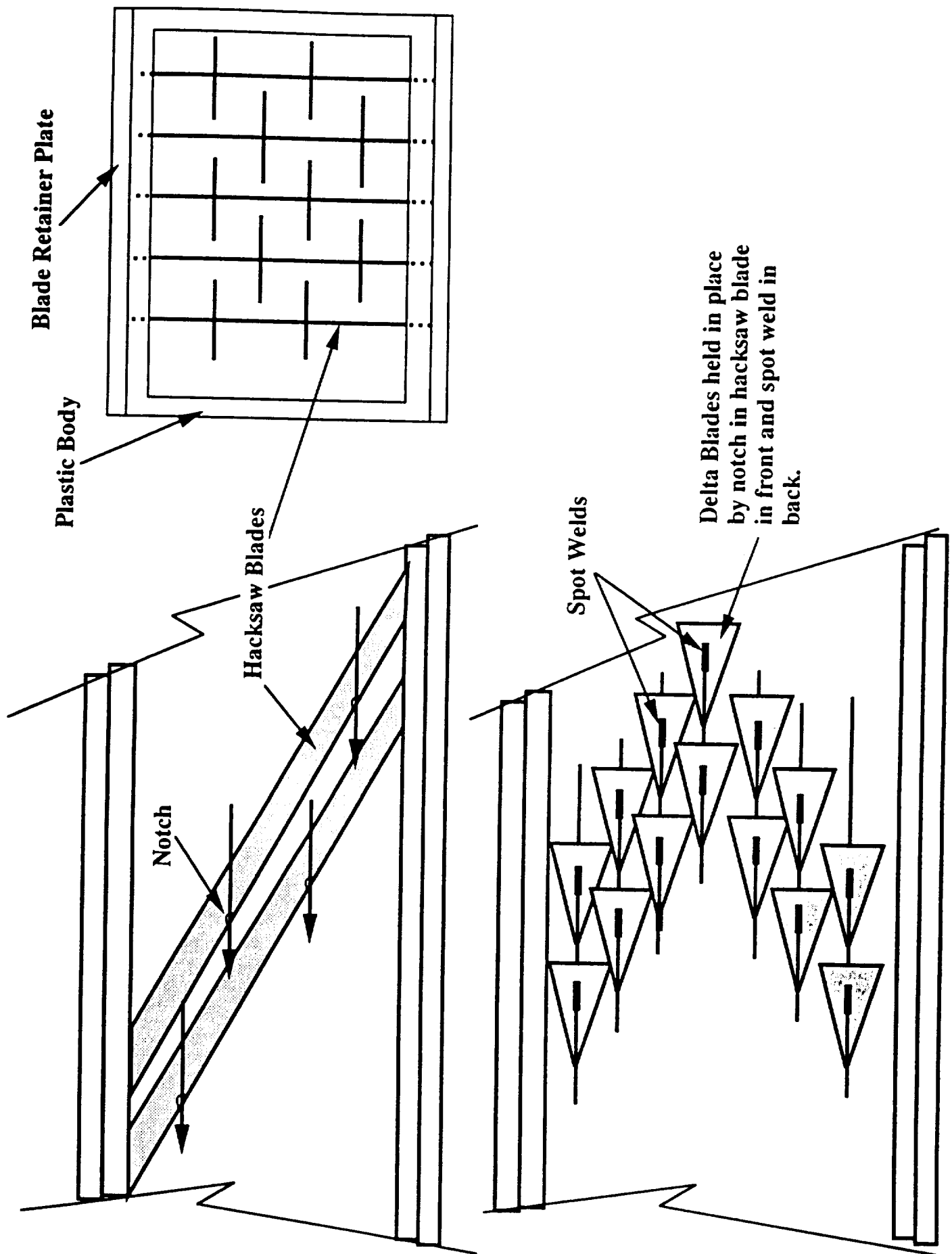
The first series of tests with this new cutter assembly indicated very high frictional forces. A raw, peeled, potato would start passing through until friction built up to a point where it would no longer move. At this point, more than 40 kg of force was being applied. There are a couple of factors that might explain this.

STATIC FRICTION

The ratio of static friction to dynamic friction determines how a block attached to a spring and pulled at a steady rate across a flat surface will move. The movement may be an initial jump settling down to a reasonably steady motion or, if the ratio of static friction to dynamic friction is high, it will continue to move in fits and starts. The latter mode seems more characteristic of potatoes. In a succession of tests with the Cuisinart-type and KitchenAid-type slicer/dicer, the ratio of the force required to move a potato through the blades from a stationary position to the force required to keep the potato moving once it had started to move was approximately 5:1. The ratio held true whether it was a whole potato or merely a slice that was being forced through. (The ratios are approximate because while it is possible to get a precise reading of the initial force required, it is difficult to obtain a reading for a force required under dynamic conditions.)

COEFFICIENT OF FRICTION

Raw potatoes are not particularly slippery, i.e., they have a high coefficient of friction. The potatoes used in tests were fairly uniform in size, and weighed approximately 200 gm each.



By microwaving them for one minute, the coefficient changes dramatically. The potatoes are still firm enough to peel, but become quite slippery. As a result, it took only half the force to push one through the five-blade, and 40% of the force through the seven-blade throats. It was also possible to force one through the "Blue Angel" configuration.

CONCLUSIONS

Cutting of potatoes for shoestrings or dices should be done at comparatively high speed.

Since potatoes destined for fries are usually blanched and dried before frying, microwaving them initially would not appear to adversely affect the ability to handle them, nor would it be detrimental to subsequent steps in processing or cooking them.

If pre-microwaving is employed, the "Blue Angel" configuration would provide a simple, compact system for making fries and dices. However, the Cuisinart-type system works very reliably, and its only drawback is that the length of the fries is governed by the width, rather than the length of a potato.

The "V" shaped fries observed with the K-Tec-type cutterhead provides crisper fries faster than the traditional shapes.

Unless there is a specific need for the traditional square or rectangular cross-section fries, it would appear that the most practical, easiest to make, and least troublesome in terms of small particles, is the wedge cut.

FLAKER/CRACKER

Few of the unit operations/products identified in the flow diagrams required flaking/cracking, nonetheless it may be a useful mechanism for providing product differentiation. Small units adequate for CELSS operation are available. These are usually powered by a manual crank which drives a series of knurled rolls with adjustable clearances. Most of these units are made in Europe. Adapting such a device for CELSS/zero-gravity operation would involve modifying the drive for use with a drive unit and designing a shrouding arrangement which would aspirate materials to be flaked/cracked through the unit and into a desired receiving container. Figure 14 shows a small commercially available flaker which is designed as a manually-cranked unit but which could be readily adapted to a drive unit.

GRINDER/CHOPPER/MINCE

A number of both powered and manually driven grinder/choppers were evaluated including both KitchenAid-type and K-Tec-type units. The KitchenAid-type unit weighed approximately 11 Kg and provided approximately 300 Watts power compared to 5 kg and



SMALL SCALE CRUSHING/FLAKING MILL

Figure 14

1300 Watts for the K-Tec-type. Based on weight and power, it would appear that the K-Tec-type would be the better suited for CELSS operation. Both types of units would require modification for zero-gravity operation. The modifications would consist of lengthening the throat to enable it to hold more product, incorporating a positive feed feature in the neck, providing an aspiration plenum at the base of the throat to carry products into the screw, and a means of collecting the material exiting the unit.

DEHYDRATOR

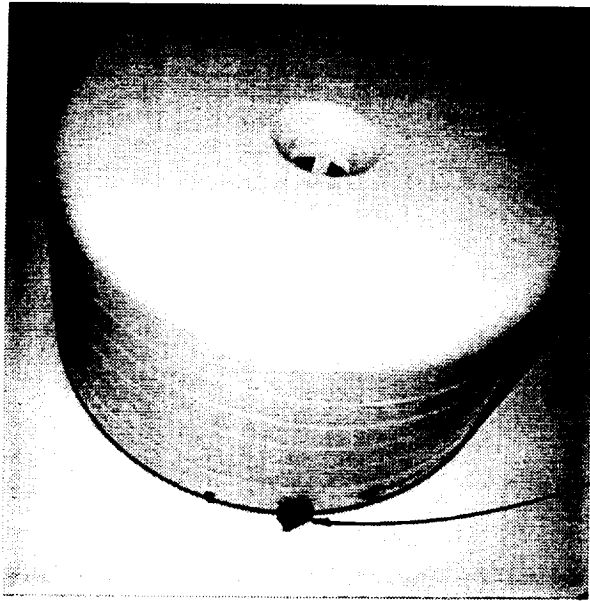
A number of small scale dehydrators were studied, and two configurations, a rectangular unit of the Magic Mill-type and a cylindrical unit of the American Harvest-type were evaluated in laboratory tests. Both configurations performed adequately in the brief tests conducted, however, the cylindrical unit provided greater uniformity. Positive features provided in this design include a fairly powerful fan, an air plenum that provides comparatively uniform air circulation across all of the trays, and a port for venting high moisture air. Figure 15 shows the general configuration of the unit. The bottom photograph shows the center location of the fan, and the air slots around the periphery of the unit. The center photograph shows the plenum that is at the periphery of each tray.

PASTA PRESS (PIZZA)

Despite the limited range of materials available for use as toppings, pizza would appear to be a potentially popular item on the astronaut menu. Normal preparation would involve successive passes through rolls to achieve the desired dough thickness. Apart from personnel involvement in the sheeting process, this operation requires considerable use of flour to prevent sticking. The difficulties posed by maintaining positive control of these fine particles preclude use of the roller-sheeter technique. An alternative available for very small scale operations involves manual or hydraulic pressing of the dough between two non-stick platens. To facilitate pressing, the commercially available units can be supplied with optional platens that can be heated to increase dough plasticity. Figure 16 shows a design analogous to those commercially available.

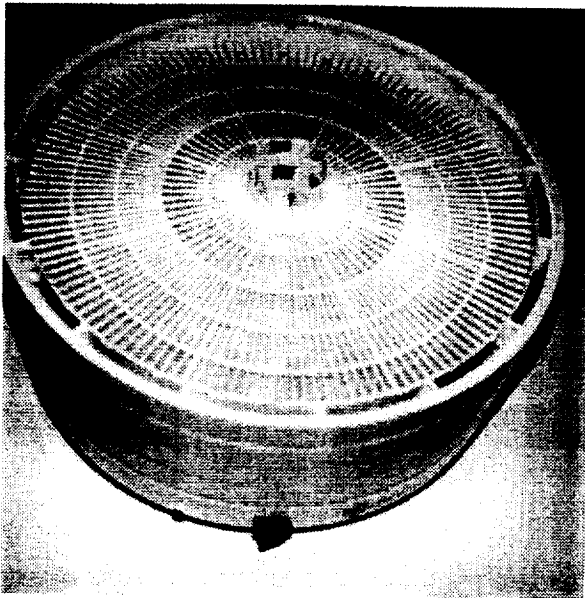
OVEN (BAKE, FRY, STIR-FRY)

Of the various cooking options examined, the high air velocity oven appears one of the most versatile. The basic concept behind the design is to use high velocity air as a heat transfer mechanism to shorten cook times. Conventional convection ovens have an air flow velocity in the neighborhood of 60 M/min., while air velocities claimed for the oven tested for CELSS ranged as high as 670 M/min. There are now several units commercially available based on this relatively recently implemented technique. Because of the newness of this oven and the



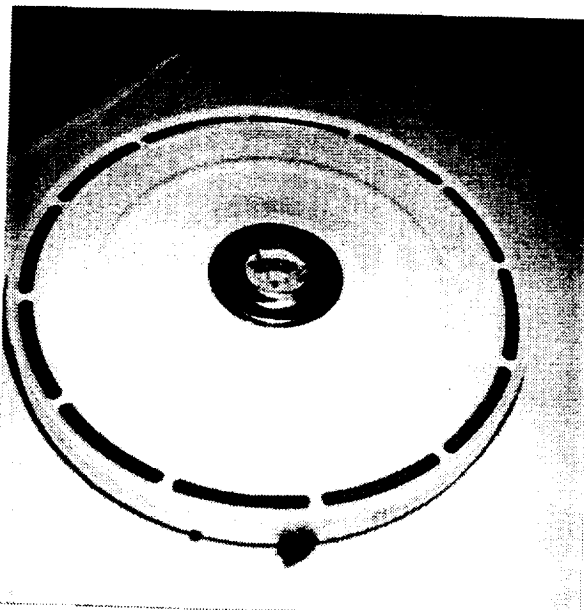
General configuration showing tray stack and centered top port for venting air.

Temperature control knob



View of tray, showing peripheral plenum, center column for air return, and tray slotting pattern.

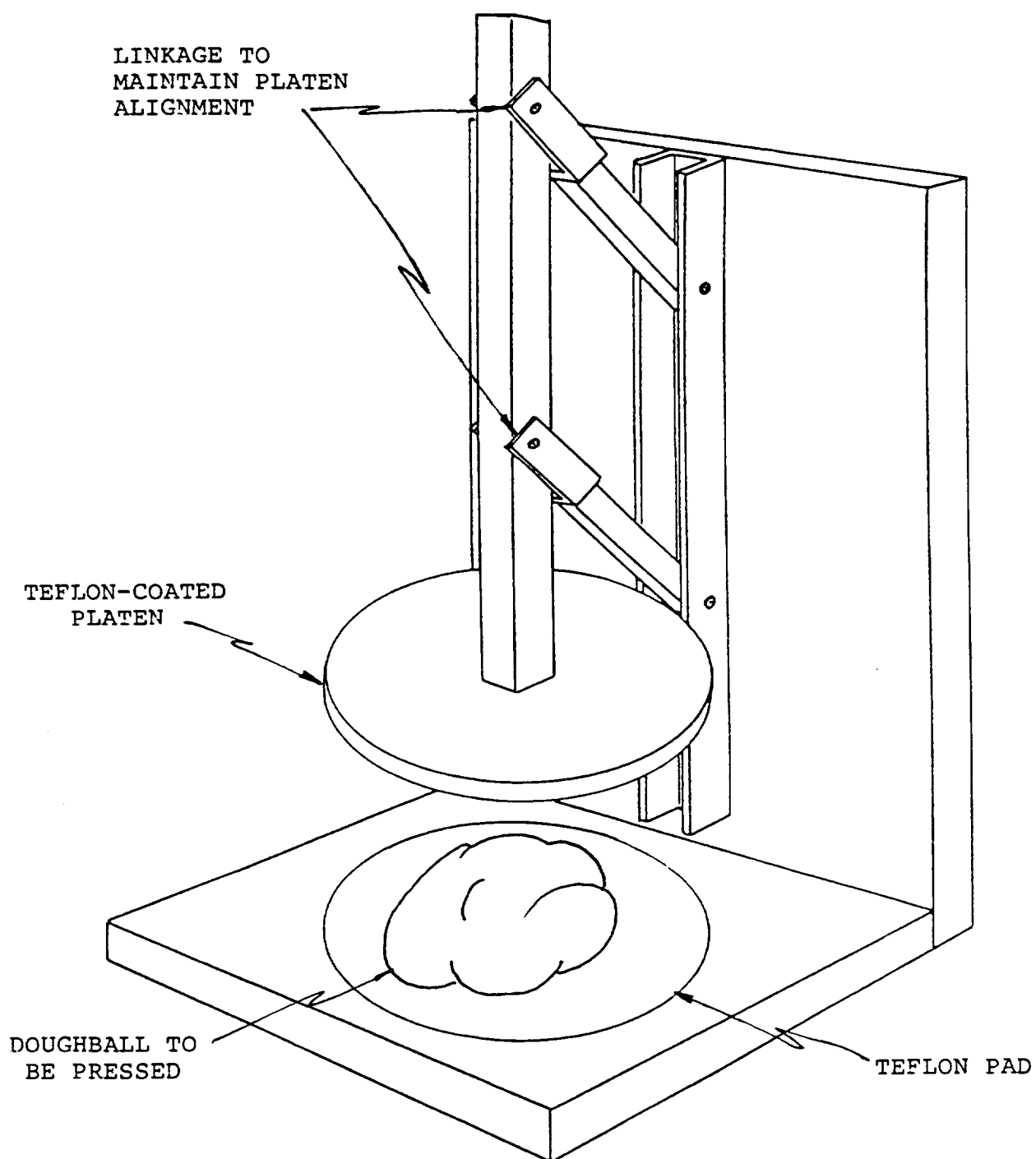
Note major air pattern is from the peripheral plenum across the tray to the central air return, not up through the stack.



View of stack base, showing circulation fan, the port for air return, and the ports for the peripheral air plenum.

The American Harvest Dehydrator

Figure 15



TEST DEVICE TO EVALUATE PRESSING AS A MEANS OF FORMING
DOUGH AND OTHER FOODS (i.e., MAKING PIZZA SHELLS)

Figure 16

absence of widespread experience in its use of knowledge of the limits of its capabilities (especially for CELSS-type ingredients and products), several test runs were required before conclusions on its suitability for CELSS could be made with confidence.

Two types of units currently on the market are the Decosonic-type and the American Harvest-type. The former represents those units intended to work in conjunction with a microwave oven. The latter type represents the free-standing, counter-top-type unit. The actual unit considered of the microwave-type consisted of a microwave transparent glass enclosure which contained the food to be cooked, and a battery-powered fan to circulate the air within the enclosure. The entire unit is designed to be placed in a standard microwave oven, with the microwave unit supplying the heat energy, and the Decosonic the power to move the air. Disadvantages that accrue from this approach include a required cooling down period between runs, and a limitation on operating time imposed by the need to recharge the batteries that power the fan.

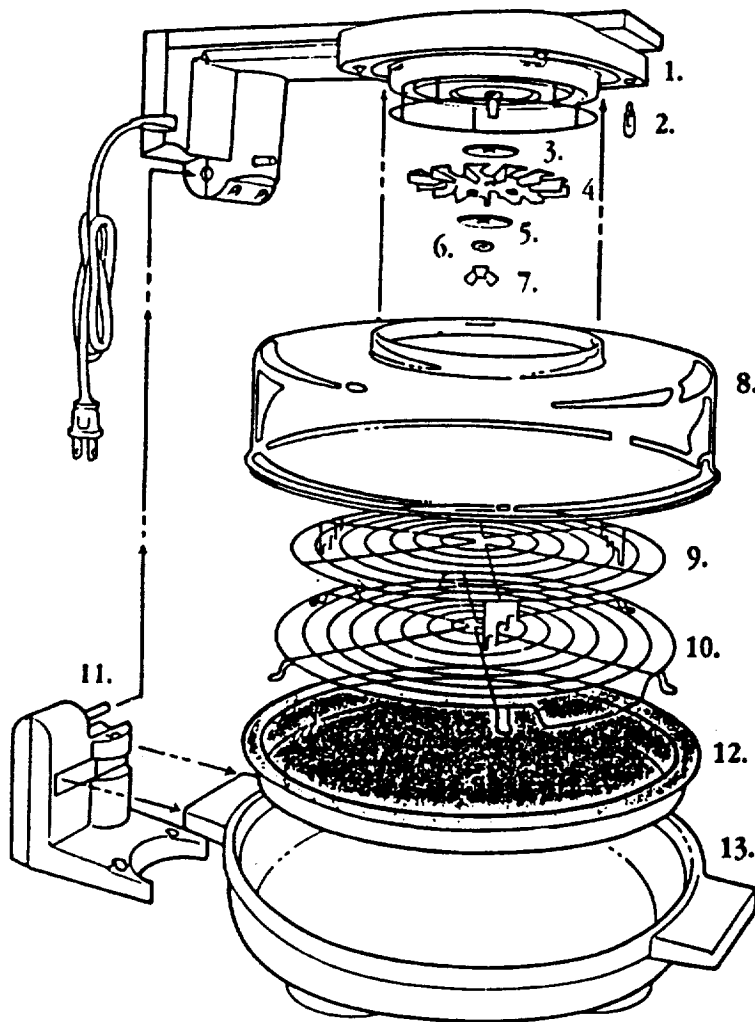
Because of these constraints, the American Harvest (AH) unit was selected for laboratory trial. This unit consists of a transparent, unbreakable plastic housing to enclose food being cooked, a 1500 Watt heater, and a fan claimed to provide air velocities in the cooking enclosure on the order of 670M/min. Figure 17 is an overall view of the unit, and Figure 18 an exploded view showing the essential components. Expander rings can be incorporated to increase the height of the cooking chamber to accommodate poultry up to a claimed 6.3 Kg and roasts. The counter space required during use is 42 cm X 34 cm; unit height without expander rings is 20 cm., however, the need to tilt the lid to add and remove product requires an available height of 46 cm. Upright storage is possible. Area requirement then becomes 20 cm X 34 cm. Useable internal chamber height without expander rings is 13 cm. Weight of the basic unit assembled but without food product is 2.7 Kg. The transparent housing was removable from the power head with a 90° twist. The power head contains the heating element and the fan, which is belt driven in the present unit, and direct drive in the new models. Two fan speeds are available. Operating temperature range is 65 to 205°C, with most cooking performed in the range of 177 to 205°C. It appears that the cylindrical configuration is necessary for the desired cyclonic effect. These performance specifications are from the supplier's literature and were not remeasured or otherwise confirmed. The plastic base of the oven contains a removable round metal pan insert which serves primarily as thermal protection for the plastic base. This pan insert is coated with non-stick material and is easy to clean. There is a bottom rack which can be set at either of two levels, and a hold down rack that is adjustable to any of four preset heights. Additional racks can be used as the oven is expanded. Product can be cooked directly on the racks, wrapped in foil, or on flat metal pans. For zero-gravity applications, the racks can be fitted with clamps for firm positioning.

The Jet-Stream OvenTM from American HarvestTM



Figure 17

Parts Diagram and Glossary of Terms



1. **Fan assembly** - houses the mechanical components of the oven.
 2. **Light bulb**
 3. **Space washer** - keeps the fan blade distanced from the fan assembly.
 4. **Fan blade** - spins at 4000 rpm to cook food quickly.
 5. **Space washer**
 6. **Lock washer** - allows a snug fit of the fan blade.
 7. **Wing nut** - secures fan blade to the fan assembly.
 8. **Lid** - see-through dome of the cooking enclosure.
 9. **"Top"/"Hold-down" rack** - serves as a "hold-down" rack for lightweight foods and at times may be used as a second cooking level.
 10. **"Bottom" rack** - upper and lower positions offer 2 levels of cooking.
 11. **Hinge pin assembly** - connects to both the fan assembly and handle/leg of base. Provides a hinge when lifting the lid.
 12. **Silverstone liner** - prevents the base from reaching undesired temperatures. Allows easy cleanup.
 13. **Base** - bottom of the cooking enclosure.
- To order replacement parts call 1 (800) 288-4545.

Figure 18

The following paragraphs describe a series of experiments conducted to: 1.) evaluate the versatility of this unit, 2.) assess its cooking speed and efficiency in terms of product preparation - claims that these were equal or approached those times achievable by microwaves for equal amounts of product, 3.) confirm that there was a satisfactory development of color, surface texture, and flavor that is frequently lacking with microwave heating, 4.) determine the effectiveness and scope of product preparation provided by a single, controlled, directed energy source (forced hot air), and the rack designs, 5.) investigate the functionality of the light-weight, compact and component-accessible design, its ease of cleaning, and minimum need for ancillary cookware, and 6.) determine its overall suitability for CELSS relative to the unit operations required and the representative products as shown in Figure 19.

EVALUATION OF THE AMERICAN HARVEST HIGH AIR VELOCITY OVEN

Figure 20 is a comparison of the oven's claimed abilities with FASI's assessment of CELSS requirements. A preliminary trial was made using manufacturer's instructions. The results of this trial, using longitudinally quartered potatoes demonstrated that accelerated cooking was indeed possible using the high air velocity concept (Appendix A, experiment 1). The subsequent testing program was aimed primarily at establishing basic feasibility, and consequently were more generic than product-specific. More work would be required to establish optimum formulations and procedures. Table 1 lists the ingredients and products that were used and considered representative of those available from CELSS crops. The following paragraphs describe the individual tests and findings in a condensed form. More detailed information on the tests is presented in Appendix A.

RESULTS OF THE CYCLONIC OVEN TESTING PROGRAM

1.) COOK/STEAM

Two sets of products were used in this trial: the first set consisted of 0.5 cm thick slices of white and sweet potato. The second was comprised of sliced mushrooms and soybean sprouts. Each set was split, with half wrapped in aluminum foil (no water added), and the other half placed in a shallow (2.5 cm deep) aluminum pan with a small amount of water added and covered with foil. Both sets were cooked at 205°C and high fan speed for 9-10 minutes. When examined, the products cooked in foil without added water were overbrowned, and in spots, stuck to the foil. Those cooked in the tray with water added were well done and had a good appearance. Based on evaluation of the products, steaming is possible in the AH-type oven in a closed wrap or container, if water is added.

Gluten meat balls, a meat analog, requires a boiling water cook for 25 minutes as a first step in its preparation. The same effect was achieved in the AH-type oven by heating them with water in a closed shallow tray for 12 minutes at

CYCLONIC OVEN CELSS APPLICABILITY TESTS

UNIT OPERATION	PRODUCT OR PROCESS
COOK/ STEAM	White potato slices Sweet potato slices Gluten - meat analog, Step 1 Soy bean sprouts Sliced fresh mushrooms
BAKE	Pizza (with CELSS ingredients) Casserole (5 cm deep dish; CELSS ingredients) Gluten - meat analog, Step 2
FRY (IN OVEN)	White potato ranch fries Sweet potato ranch fries White potato French Fries Pancakes (in a hollow platen)
STIR FRY	Mix of: White and sweet potato strips Chopped soy bean sprouts Pieces of tempeh burger Slices of tofu frankfurters Sliced fresh mushrooms
PUFF	Gluten - meat analog (as a snack)
TOAST	Bread slices
ROAST	Wheat berries (for hot beverage extraction)

Figure 19

**PRELIMINARY COMPARISON OF A/H OVEN CAPABILITIES AND
CELLS PROCESS AND PRODUCT REQUIREMENTS**

Unit Operation	Wheat (W)	Irish Potato (WP)	Sweet Potato (SP)	Soy Beans (SB)	Intermediate or Final Product (1)
Parboil/ Dry cook(2)	●	●	●	●	W-Bulgur, Porridge, Cereal WP-Plain, Mashed, Scalloped, Salad SP-Plain, Waffle batter, Puree, Syrup Confectionery SB-Plain, Meat analogs
Toast	●			●	W-Hot beverages, Toasted bread SB-Soy cereal, Beverage
Bake	●	●	●	●	W-Bread, Cakes, Pretzels, Pastry WP-Plain, Puffs SP-Plain, Muffins SB-Crackers, Pretzels
"Deep fat fry"(3)	○	●	●	●	W-Doughnuts WP-French fries, Peel chips, Potato chips SP-Chips, Snacks SB-Soy snacks, Tofu, Tempeh
Cook & fry		●	●		WP-American fries, Hash browns SP-Fried sweet potato, "Leathers"
Grill/ pan fry(4)	●	●	●	●	W-Pancakes, Waffles, Crepes, Flat bread WP-Pancakes SP-Pancakes SB-Pancakes, Waffles
Roast				●○	SB-Soy nut snacks, Meat analogs, Tempeh, "Coffee" beans
Steam	●○		●	●	W-Pasta, Dumplings SP-Greens SB-Greens
Boil/ simmer(5)	○			○	W-Hot beverage SB-"Coffee", Soymilk
Cook & extrude	X			X	W-Puffed snacks SB-Puffed snacks, Oil extraction

KEY: ● High probability of success
○ Requires tests and/or modifications
X Not suitable

Figure 20a

Notes:

- (1) Based on flow charts and matrices as updated to May 1992.
- (2) Absence of excessive or "free" liquid.
- (3) Procedure involves coating with oil followed by hot air or other non-immersion heating.
- (4) Will require flat hollow platen to receive and assure flat configuration of product in zero gravity.
- (5) Probably more efficient to use immersed resistance heater for water.

Figure 20b

Table 1

*

"CELSS" INGREDIENTS USED FOR CYCLONIC OVEN TESTS

Fresh white (Irish) potatoes
Fresh sweet potatoes
Soy bean oil
Soy bean sprouts
Tofu (soft)
Tofu frankfurters (pups)
Tempeh
Tempeh burgers (hamburger analogs from tempeh)
Fresh mushrooms (assuming availability from biomass)
Cheese product made from soy ingredients
Wheat berries (basis for hot beverage)
Gluten based meat analog (wheat ball mixture)
Wheat flour - as pizza crust
 as pancake ingredient
 as bread slices
Skim milk - as pancake ingredient in lieu of soy milk

* Major ingredients, same as or suitable substitutes for those available from CELSS crops and/or processes.

205°C and high fan speed.

2.) BAKE

A "CELSS" pizza, containing whipped tofu spread over a wheat flour pizza shell (as a substitute for tomato paste) plus strips of tofu mozzarella cheese alternative, chopped soybean sprouts, and 0.4 cm thick slices of tofu frankfurters randomly placed on the surface, was successfully baked in the oven. After baking at 190°C for 45 seconds to set the ingredients and 5 more minutes at 205°C and high fan speed, the pizza was well done, the shell was crisp, the topping was hot, and the color was a pleasant brown on peaks and raised areas.

The single dish meal concept was extended by baking a casserole in the oven. Sweet and white potato slices, tofu frankfurter slices, and pieces of tempeh in a tofu "sauce", all in a 11.4 cm diameter and 5 cm high Pyrex dish with soy cheese slices laid over the surface were heated at 204°C for 7 minutes at high fan speed. Some preheating of the tofu "sauce" had taken place in a microwave oven and the potatoes had been separately partially cooked in the AH oven. Based on examination of the product, it appears the precooking can be eliminated.

3.) FRY

Ranch fries, potatoes sliced longitudinally into quarters or eights, have been successfully "fried" in the AH-type oven at 205°C, with high fan speed, for 9 minutes on the wire racks. To simulate deep fat frying, the exposed surfaces of the potato slices were coated with edible oil. This provided surface and flavor characteristics similar to those commonly associated with deep fat frying techniques. An additional coating of grated cheese further enhanced appearance and acceptability.

Potatoes cut into french fry strips were similarly coated with oil and prepared in the oven. Racks can be used; however, excellent results were obtained by simply allowing the cooking pieces to whirl freely around the oven chamber. Specifically noteworthy was the uniformity of browning.

Addition of oil to coat fries in zero-gravity conditions poses a material handling problem, both in terms of potential oil contamination and handling the slippery fries. Several alternatives were investigated. The most effective and easy approach involved doing the coating in a plastic bag. Standard market potatoes weigh about 300 gms, and provide a satisfactory single serving of fries. Cutting a 300 gm potato directly into a resealable Ziplok or comparable plastic bag, adding about 5 ml vegetable oil, sealing the bag and massaging it for a few seconds appeared to provide adequate distribution of the oil. An important factor in the effectiveness of this procedure may be the size of the bag. Too large a bag may not provide as uni-

form oil distribution as desired. The bag used in these trials was an ordinary sandwich bag.

An observation on french fry cutting might be appropriate. French fries come in a number of cross-section cuts and sizes including square-cuts, rectangles, and wedges, which provide various surface to volume ratios. Since crisping is very much affected by this ratio, it should be possible to achieve a crispy or uncrispy fry by varying the shape. Trying fries cut in the "V" pattern using a K-Tec cutting head and using the oiling technique described above in the high air velocity AH oven resulted in random-size and shape potato pieces that had the crispness of a potato chip, but with flavor, and odor about half-way between a chip and a french fry.

4. PANCAKES/WAFFLES

Because of zero-gravity, standard grilling of batter-based products, such as pancakes, are not feasible in CELSS. Through the use of a thin, shallow dish (about 1.3 cm deep) with a lid, and with the high heat transfer rates possible with the AH oven, it was felt possible to prepare pancakes for astronaut crews in much the same way as waffles, by cooking them in a pan which cooked them on both sides simultaneously, obviating the need for flipping. Figure 21, 22, and 23 show a procedure for accomplish this. The figures show a shallow dish used to evaluate the feasibility of this concept open and with the batter inserted and the lid attached, ready for cooking. By filling the dish with 150 cc batter, and cooking at 205°C for 5 min., the end product was a very acceptable pancake, browned on both sides, without the need for turning the dish during the process. In practice, the shallow dish could be a hinged clamshell design with non-stick coated surfaces. It is anticipated that the batter would be injected into the dish with a syringe. The dish would need to be comparatively cool at time of filling to avoid immediate setting of the batter during the process. The dish would also need to be easily opened for product removal and cleaning, and of low mass for quick cooking/cooling, and handling.

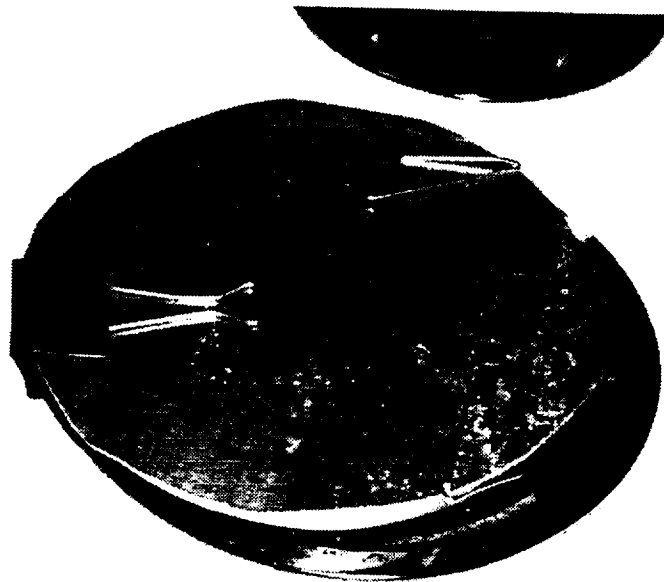
5.) STIR-FRY

Stir-frying is usually done in a wok or fry pan with a small amount of oil or sauce over high heat. The product, usually a mixture of vegetables with small strips of meat or seafood is stirred vigorously to allow all surfaces to be seared to an acceptable level of "doneness" without being scorched.

Two separate procedures were tried with the AH oven to determine the suitability of high air velocity ovens for stir-frying. In the first test, a mixture of soy sprouts, mushroom slices, and bits of tempeh burger were sprayed (or otherwise coated) with edible oil (PAM or a similar material was used for these test). The product was



Batter in platen bottom prior to covering and cooking

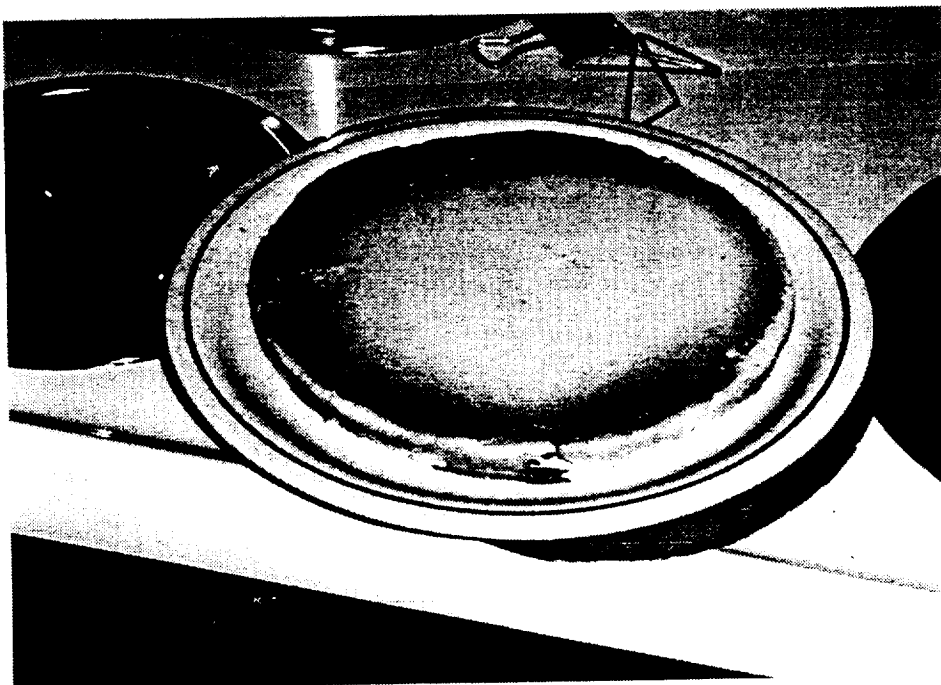


Sealed pancake batter filled platen ready for cooking.

Figure 21



Top view - pancake as removed from A/H oven after 5 minutes at 204C



Bottom view - pancake as removed from A/H oven after 5 minutes at 204C

Figure 22



Cross section - Pancake from A/H oven after 5 min at 204C



Top view - Seventy-five cc batter (partial fill) pancake from A/H oven after 6 minutes at 204C

Figure 23

placed between two racks in the preheated oven and cooked for 10 minutes at 205°C and high fan speed. The resulting product had the general flavor and texture of a stir-fried product.

In the second trial, small amount of oil was spread in the bottom pan of the preheated AH oven. A mix of normal stir-fry ingredients were combined, and added. Cooking was done at 204°C with a high fan setting. The resulting product had the flavor and texture of a normal stir-fried product. Based on these trials, the AH oven would appear very suitable for making stir-fry in a CELSS with only minor changes to adapt it to a zero-gravity situation. The major question may be one about loading or throughput.

6.) PUFFING

Tests have not yet been carried out to confirm the procedures outlined in Appendix B. It was, however, noted that the smaller of the wheatballs did puff somewhat, browned and crisped very nicely, and were tasty, more characteristically a snack than an entree item.

7.) TOAST

Three slices of wheat bread were placed between two racks in the oven and heated for 4 minutes at 205°C and high fan speed. The result was excellent toast, browned and surfaced crisped on both sides with the center remaining soft.

8.) ROAST

Roasting in the CELSS context, has been applied to heating wheat berries long enough to cause changes that when the berries are then ground to a powder and leached with hot water, an acceptable hot beverage is realized. Wheat berries heated for 30 minutes at 205°C in a 1.6 mm mesh basket, then milled, resulted in a beverage which was somewhat more bitter than coffee, but certainly not unpleasant. Additional research will be required to establish optimum roasting parameters and to examine the hot beverage potential of soybeans and sweet potatoes.

Based on the foregoing, the American Harvest Jetstream (cyclonic) oven or its equal is recommended for inclusion in the food processing and preparation equipment list for CELSS. It is an effective, versatile heating and cooking unit using a single heat generation mode, as demonstrated on these selected trials. Some design changes such as increasing its size for larger crew support, and designing food and accessory restraining systems for zero-gravity may be necessary as the specific criteria for CELSS become better defined.

Test runs made with the AH-type oven, used as accurately as possible, CELSS available ingredients and appropriate substitutes, covering sweet and white potato quarters, pizza and casserole one-dish meals, ranch-fried potatoes, stir-frying,

pancakes, steamed/water cooked vegetables, gluten meat analogs, toasted bread slices, and roasted wheat berries as a source of a hot beverage. These tests were broad enough and successful enough to conclude that, when also considering the compactness, cooking speed, size/weight, product visibility during the cooking cycle, and ease of operating and cleaning, the AH-type oven is a very useful and legitimate CELSS item. A separate matter from performance, but highly relevant, is the matter of safety. The operating temperatures used in the AH oven would be more than sufficient to cause painful burns. In the case of housings made of glass, this and the danger of breakage would be areas of major concern. In the case of the American Harvest unit, the selection of an unbreakable polymer which does not conduct heat well, reduces the hazard to a level where the transparent housing would feel hot to an astronaut inadvertently touching it, but would not cause burn injuries.

MICROWAVE OVEN (HEAT, PUFF, BROIL, BAKE)

Because of their inability to brown products, their mass dependency, and the temperature variability caused by nodes, as well as advances in appliance design, microwave ovens are being severely challenged by both convection ovens and high air velocity ovens. Nonetheless, microwave units offer certain unique features that would be useful in a CELSS food system. Microwave ovens heat by inducing rapid fluctuation in the orientation of polar molecules including water and most inorganic salts. Consequently, with the exception of nodal hot spots, products being warmed in a microwave unit tend to warm rapidly and fairly uniformly, so that a bagel heats in about 25 seconds, and popcorn can be popped in about 3 minutes. To extend and build upon these capabilities, considerable effort has been devoted by Natick Laboratories to improve microwave units for use in field kitchens. One of these advances has been the replacement of the Magnetron tube, which had to be protected from spatters and vapor deposition, by antenna(s) which can be positioned within the cooking chamber and can also serve as resistance heaters to do broiling or baking. Incorporation of fans/blowers to provide sufficient air circulation enables these units to also function as convection ovens.

Table 2 is a listing representing some commercially available and some advanced prototypes of microwave multi-energy ovens along with their existing additional heating modes. All of the versions listed are functional, and selection of specific designs or models becomes, to some extent, judgmental and subjective.

The "SPEED" oven, Figures 24 and 25, with the addition of a hot air convection system would be the first choice. This oven was developed for the U.S. Army in its search for efficient mobile field food service units. The overall system was not fielded because overall costs, that included on-board power generation, were too high. However these unique ovens functioned well. They featured six power modules, each delivering 1.25 KW of microwave power at 2450 MHz. The modules supplied microwave

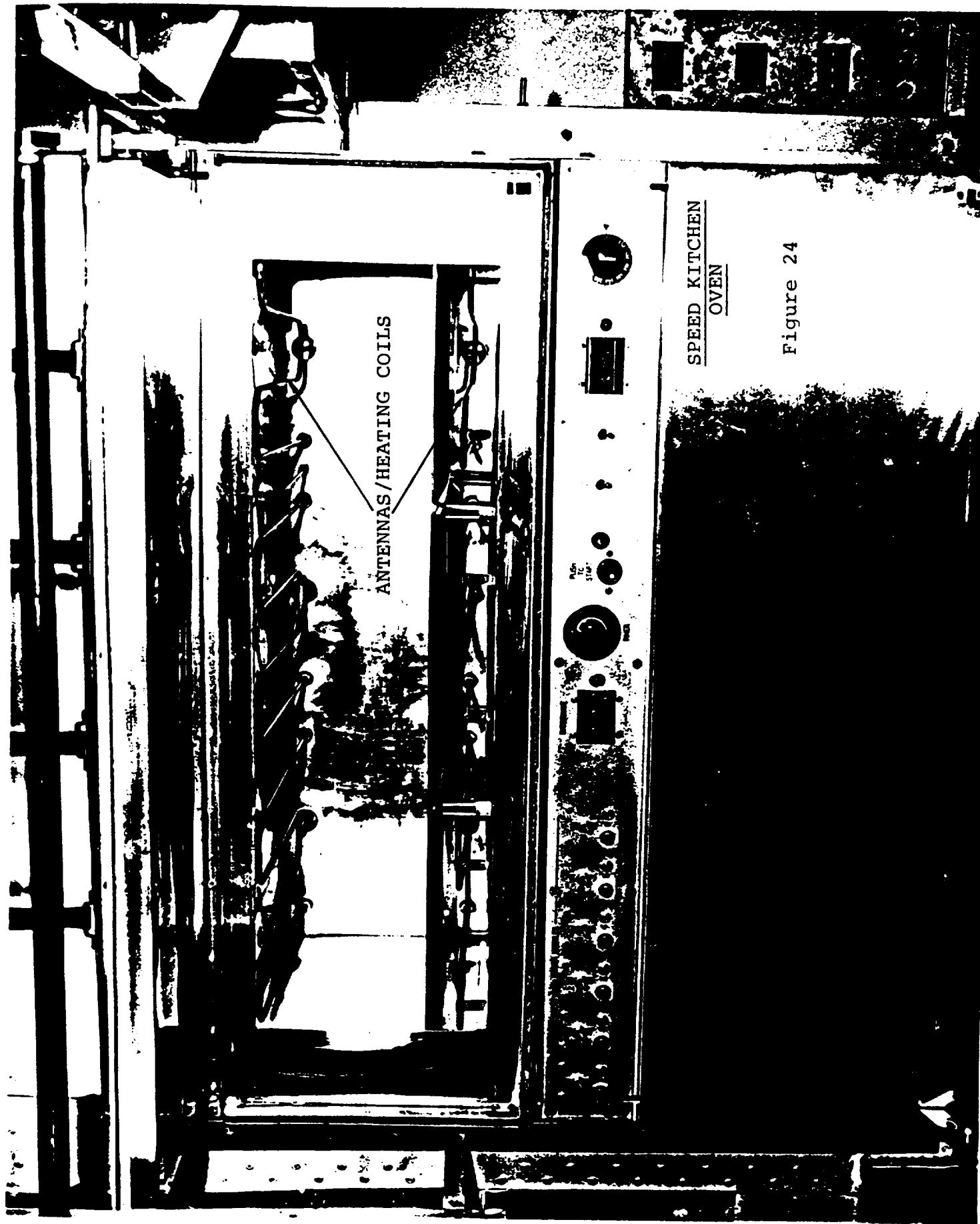
COMMERCIAL MULTI-ENERGY OVENS
(MICROWAVE PLUS OTHER MODES)

MANU- FACTURER	MODEL OR COMMON NAME	MICRO WAVE	HOT AIR CONVECTION	RADIANT INFRARED	STEAM	CONDUCT- TION
RATHEON	MULTI-ENERGY(1)	o		o	o	
LITTON	SPEED (2)	o		o		o
BONNET	ENERGY-3	o	o		o	
LITTON	JET-WAVE	o	o			
PRECISION SCIENTIFIC	MICROWAVE- CONVECTION	o	o			
RAYTHEON	RADAR/PROOF 'N BAKE (3)	o	o		o	
PHILIPS	MULTI-M	o	o	o		o
NEFF	COMBO M-W OVEN	o		o		
CANDY	COMBICHEF	o	o	o		

NOTES - "o" designates capability

- (1) Laboratory experimental oven fabricated for and used by the U.S. Army Natick RD & E Center.
- (2) Custom designed and built ovens for prototype mobile field food service unit for the U.S. military.
- (3) Designed for in-store retail proofing and baking system, that, because of marketing decisions, was not transitioned to full scale production.

Table 2



SPEED KITCHEN
OVEN

Figure 24



SPEED KITCHEN OVEN

Figure 25

SPEED KITCHEN OVEN

Figure 25

power to three W-shaped antennas near the cavity's ceiling and three near the floor. These same antennas also provided resistance heat to the oven. It is highly probable that with a resistance heating capability already present in the oven cavity, that convection heating in the common 60M/min. velocity range could be implemented by one or more small remote or shielded fans. The overall simplicity, W-shaped antennas and fans, properly controlled, to provide microwave, radiant, and convection heating - is the basis for this recommendation.

In addition to the dual (and perhaps triple) function heater/antennas of the SPEED oven design, other triple energy source designs include:

- a. Providing the three heating modes from individual sources;
 - Single or dual magnetrons with wave guides and use of a fan-like diverter and with a thin microwave transparent protective panel for the diverter,
 - Resistance heater and fan to provide hot air with precautions taken to avoid direct exposure of the magnetrons to the heated air,
 - Single or dual Calrod element mounted near the top of the cavity and protruding into the cavity. (In some designs, there is some reliance on the radiant heat source to supplement or replace a separate heat element for convection hot air.)
- b. Use of quartz tube lamps to generate infrared radiation for both direct broiling, toasting, or roasting and convection. Magnetrons would independently generate microwave power.
- c. Use of multiple smaller magnetrons and wave guides arranged in a rectangular battery or array immediately above the product being heated/cooled. The hot air for convection heating could be guided down through these same multiple wave guides. It is conceivable that shaped radiant heat rods can be interspersed among the battery of wave guides to provide a separate or simultaneous radiant heating effect.

The state-of-the-art and general food service experience experience for combining microwaves with other heat sources are advanced and well documented in the literature and in descriptive and instructional booklets accompanying such ovens as listed in Table 2. Judgment on applicability of the M-E oven (microwave, radiant heat, and convected hot air) to the products in Table 1 was based predominantly on documentation and were positive. Using one or more of the heat sources, singly, sequentially, or simultaneously, the M-E oven can cook, bake, oven fry, stir fry, toast and roast the ingredients and products of Table 1. There were two operations - steaming from the equipment aspect, and puffing from the formulation viewpoint - that were given specific attention.

STEAMING IN THE MICROWAVE OVEN

Most microwave cooking can be accomplished in a straightforward manner in a shallow pan with foil, flexible film or even paper

toweling as a partial cover to prevent excessive product moisture loss or scorching. There may be instances where steam per se is preferred. Incorporation of a steaming feature into a microwave oven without extensive or specialized construction can be accomplished by using a microwave transparent vessel into which product in a perforated metal pan and some water are placed. Water is heated by microwaves into steam which passes through the perforations to the product.

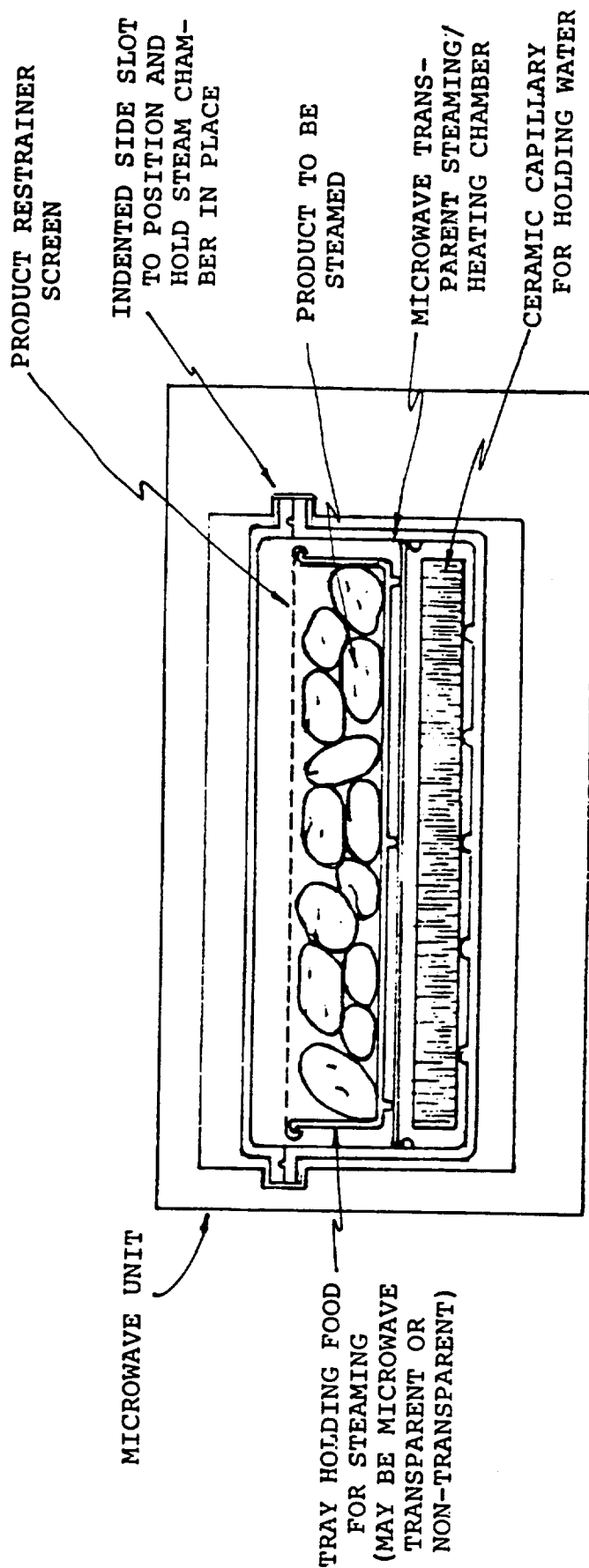
To test the ability of a microwave oven to steam vegetables, a small amount of water was placed in a microwave-transparent container equipped with a pressure relief vent. The container was closed and placed in a standard micro-wave oven. Within a few minutes after the cycle was started, the container was observed to visibly fill with vapor, generating sufficient steam to jet vapor from the vent within 4 minutes. Based on this test, steaming could be accomplished very satisfactorily in a microwave, by using a microwave transparent container with a pressure bleed. If it were desirable to cook vegetables only with steam and cancel out the effect of the microwaves, the removable container could be equipped with a microwave opaque screen basket to hold the vegetables being cooked.

Figure 26 shows a concept for a steaming chamber similar to that patented by Bowen (1982). In this concept, a microwave transparent chamber consisting of top and bottom pieces that clamp together would contain the perforated dish of food to be steamed. The dish for most applications would be metal, but, if specific product characteristics call for it, it could also be microwave transparent. Water to supply the steam would be retained via capillary action in a removable ceramic tube bundle positioned in the bottom of the chamber. In operation, the bottom of the chamber would be placed on a work surface, the ceramic tube bundle would be positioned in the chamber bottom, the dish of food to be steamed would be placed on top of the ceramic bundle, and a retainer screen would be secured to the dish to prevent food from moving during the heating/steaming process. The top of the chamber would be placed on the chamber bottom and clamped in position or held in position by the oven side wall guides. After sliding the assembly into the oven on guides, the process can be carried out at the desired power level and duration.

The concept shown in Figure 26 is a totally closed batch system; however, the unit could be constructed so that water introduction, pressure monitoring and release, and temperature sensor lead-in with release taps and plugs could be installed and positioned to mate with counterparts in the rear wall of the oven.

PUFFING

A discussion of formulations and techniques for puffed snacks using the M-E oven with CELSS available ingredients is given in Appendix B. The concept is the rapid heating of the moist center of a small food piece causing vapor generation and subsequent expansion. In summary, a mixture of 60-90% starch, in-



CHAMBER AND SYSTEM FOR STEAMING FOODS
USING A MICROWAVE OVEN

Figure 26

cluding some cooked to gelatinization; sweetener; salt; and flavoring is cooked (in a vessel or extruder) with water; dried to a final moisture content of 5 to 20%; formed into a pellets or other small shapes; and puffed by heating in convected hot air or the use of microwaves.

Screens, racks or mesh baskets will be required to position and confine products in the oven during operation in zero-gravity. Side wall slots, as shown in Figure 26, can be used for holding such devices.

PANCAKES/WAFFLES

For pancakes or waffles to be prepared in the M-E oven using radiant heat or convected hot air, a hollow clam shell platen, described above in the section on the high air velocity oven, could be used.

PROOF/SPROUT (BAKED GOODS, GRAIN, BEANS)

Proofing baked goods and germinating sprouts require basically the same type of equipment, essentially a controlled temperature cabinet with trays equipped with a restraining system.

While the astronaut diet available from soybeans, sweet potatoes, wheat, and white potatoes may be nutritionally complete, from a functional standpoint, it seems deficient in fresh greens. Of these crops, greens would include; leaves and shoots of sweet potatoes, immature soy leaves and pods, and sprouts. Harvesting plant leaves and shoots at the immature stage can, however, have a negative effect on plant productivity.

Sprouts have an advantage in that they can be available as needed, do not adversely impact yield, and can be produced from both wheat and soybeans. The basic procedure would consist of soaking the wheat berries or soybeans well in a plastic bag, draining off the excess water in a spinner dewatering device, placing the seeds in trays or canisters using an aspirating tray table, and then loading the trays or canisters into a warm controlled temperature cabinet for germination.

Virtually all baked goods involving yeast require holding at warm temperatures to permit the organisms to grow and generate carbon dioxide to make the dough raise. In the case of breads, this would normally be done in the breadmaking machine; however, there will be other baked goods such as rolls and bagels which need to be proofed in a cabinet. In these cases, the dough would be kneaded, formed, secured on trays, and placed into a warm temperature-controlled cabinet. When adequately raised, the rolls etc., would be transferred to an oven for baking.

EQUIPMENT CONCEPT DESIGNS DEVELOPED, PROTOTYPE TRIALS AND DESIGN MODIFICATIONS

TRIMMER/CUTTER/PEELER

The principal purpose of the trimming/cutting operation is to remove small defects such as eyes (potatoes), and damaged or discolored areas from the various vegetables grown in the CELSS. Inherent in this task is the need to control and dispose of the tissue removed. Figure 27 shows a manual/pneumatic system which can be fitted with various hand pieces to do small tasks such as trimming, cutting, peeling, etc. In this design, the material removed is aspirated to a collector or could be aspirated directly to waste or biomass processing

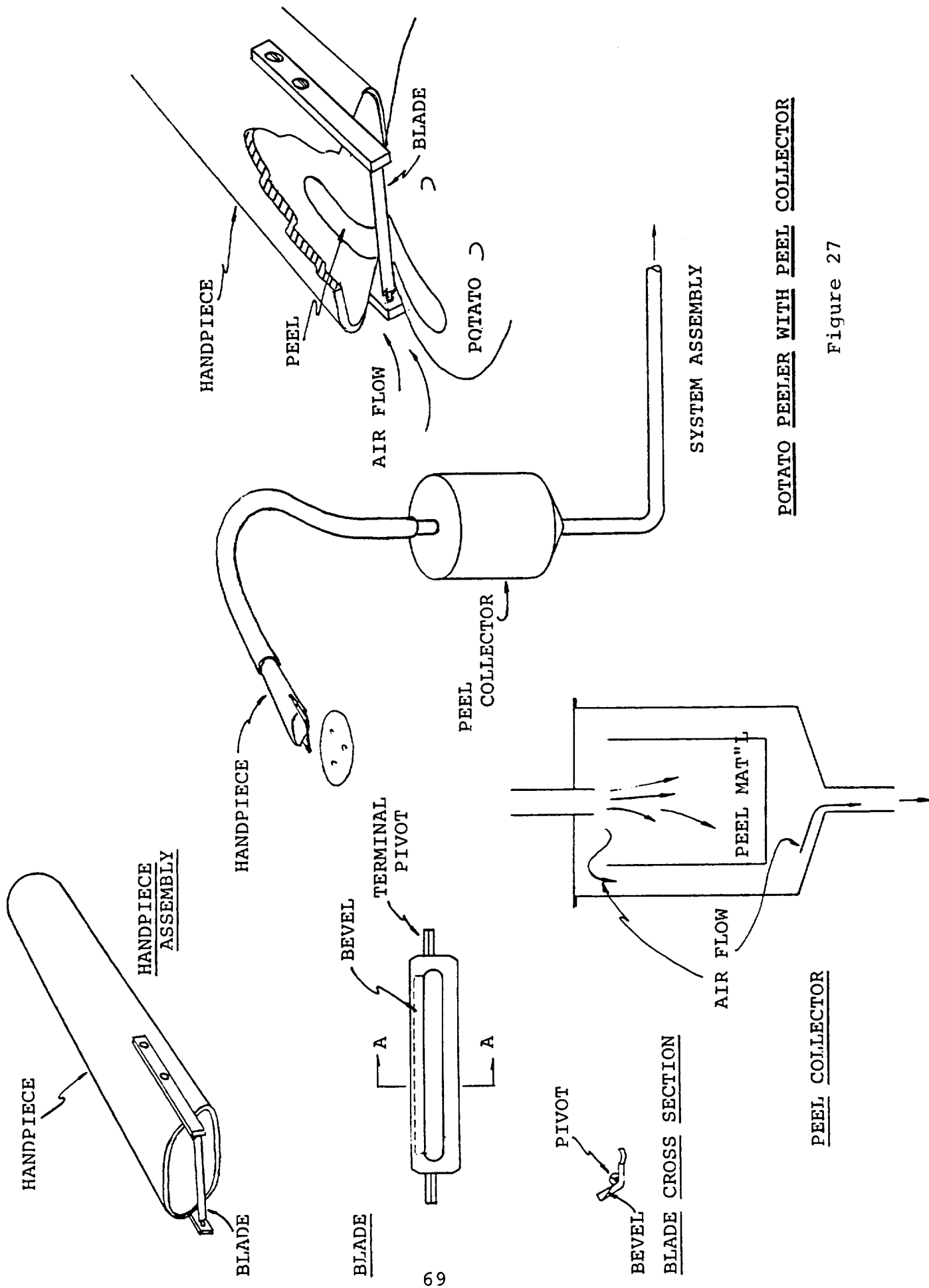
PEELER

Of the four food types studied, wheat, soy, potatoes and sweet potatoes, two require peeling for some food dishes. Because the actual number of potatoes required to make a batch of snacks or fries for a crew of 12 can be between twelve and thirty, depending on potato size, a hand operation was initially considered. The peeler consisted of a conventional hand peeler with a swivel blade connected to a vacuum source (Figure 27). Whereas a typical hand peeler works satisfactorily, albeit with some dexterity required to grasp and turn a potato in one hand while slicing it with the blade held in the other hand, the unit with the vacuum tube proved cumbersome to handle although the results were good.

However, if potato flour is required, for example to mix with a high protein wheat flour for bread, then the number of potatoes to be peeled would become excessive for a manual operation, and an automated system becomes necessary.

A small Kenwood powered hand-held peeler was evaluated. It consisted of a high-speed rotating head with four blades attached to resemble a small paddle wheel. To peel a potato, the paddle wheel was pressed on its side against the potato. The unit has a clear plastic hood to prevent excessive spatter. While the unit peeled effectively, it was not considered suitable for CELSS operations, partly because, although peeling was slightly easier, it was no faster than with a manual peeler, but primarily because of the myriad small droplets it generated. The shield only partly controlled the splatter which was mostly wet pulp. Inspection showed fine droplets of material were flung in a radius of 0.5 to 1.0 M.

The most common type of small sized, powered peeler is the commercial type which relies on an abrasive disc rotating about a vertical axis within a cylinder, also sometimes abrasive-coated. Potatoes are placed in the unit. The friction between them and the cylinder walls restrict their moving at the same speed as the wheel abrading the potato surface exposed to the wheel as they tumble randomly. Peeling may take ten minutes or more. Skin and abraded tissue is flushed away with a continu-



POTATO PEELER WITH PEEL COLLECTOR

Figure 27

ous stream of water. The system is heavy, relies on gravity, needs copious amounts of water to flush the waste, and produces large quantities of unusable sludge making it undesirable for CELSS applications.

One concept evaluated relied on partially cooking a potato, slitting the skin, then pressing it against a perforated disc. Figures 28 and 29 show a concept design and test prototype for testing this approach. At 1.75 kg/cm^2 , about 50% of the starch material was forced through the perforations, and at 2.5 kg/cm^2 approximately 80% was forced through. The rods and short segments ("riced" potato) would lend themselves well to subsequent drying operations for the production of flour. The skins can either be sliced and fried for direct use as a snack food, or dried and coarse ground for use as an ingredient in such products as crackers.

A more versatile system that lends itself better to automation without undue waste is a development of the commercial abrasive wheel concept. Instead of an abrasive disc, it uses a shredding disc of a food processor. The unit shown in Figure 30, consists of a standard Cuisinart base, bowl, and shredder disc with a 15 cm high extension to the bowl to provide an upper chamber in which to place potatoes to be peeled. Initial tests were conducted using a second inverted bowl to form the upper chamber. There were no raised "speed bumps" or vertical bars.

As the disc rotated and contacted the potato, the blades bit off thin slivers of peel and potato that were about 1 cm long and 0.5 mm thick. The slivers were discharged from the bottom of the disc and thrown by centrifugal force to the top circumference of the lower compartment. Disc friction and the impact of the cutters tended to turn the potato, exposing other portions with skin. The motion also forced the potato to the periphery of the bowl where friction caused the potato to revolve around the inside of the bowl in the manner of a planetary gear motion.

In an initial experiment with three potatoes, two were approximately $5.5 \times 5.0 \times 4.5 \text{ cm}$, and one was $7.5 \times 6.0 \times 4 \text{ cm}$. The peeling test was run for 13 seconds. On inspection, the two smaller potatoes were very clean with only a few spots of skin where there were eyes. Approximate dimensions of these potatoes after peeling were $5.0 \times 4.75 \times 4.0 \text{ cm}$. The larger potato had not rolled evenly, and ended up having a flat cut on one side. The potatoes required no washing. About 5% to 10% of the skin "fines" did not pass through the disc. They were left on the periphery of the upper bowl. The slivers were very even in size and judged very suitable for potato pancakes or snack products.

The results of the initial trials showed that the basic concept had merit, and that the process required far less time than manual peeling. The potatoes were virtually free of skin (except for eyes), and did not require washing. The initial tests also showed that the design was too sensitive to the shape of material being peeled. Objects with flat areas tended

Potato Press

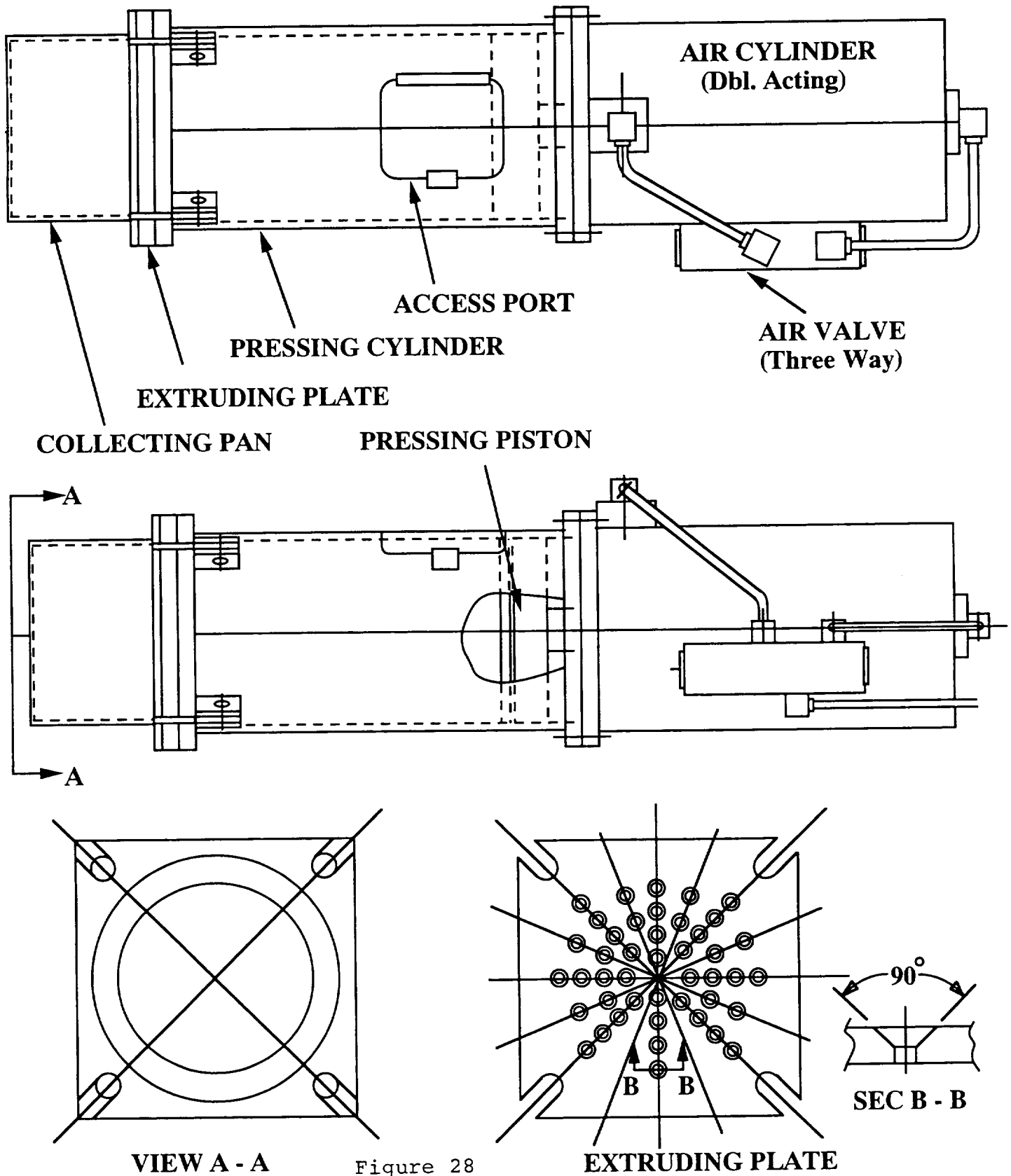
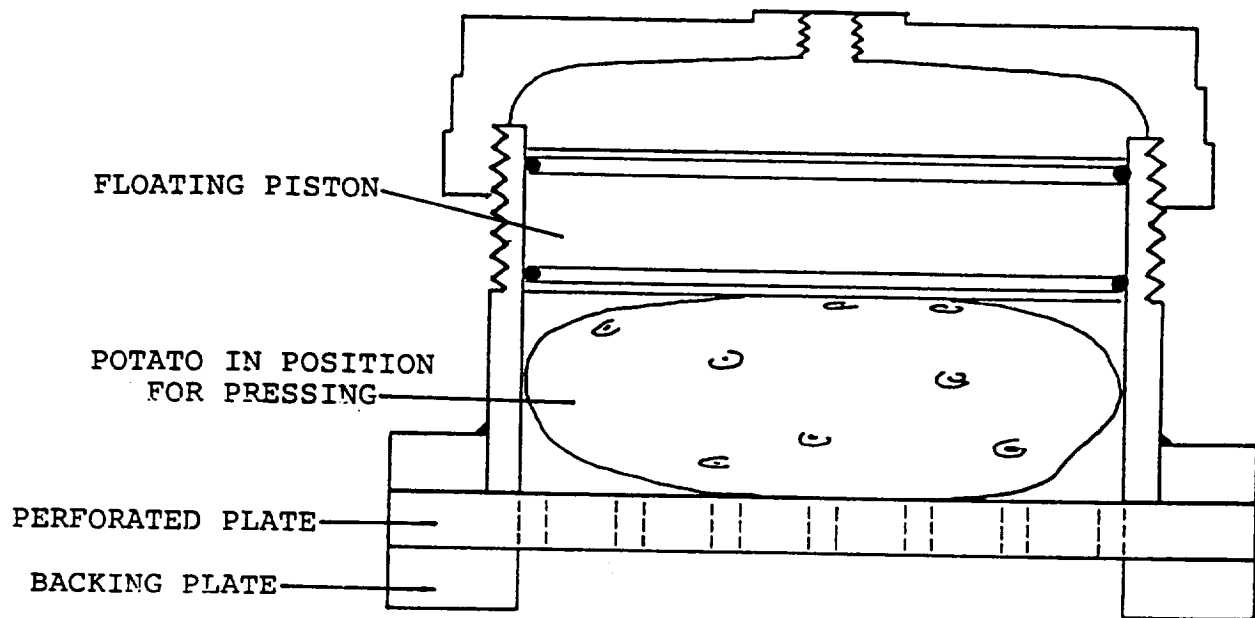


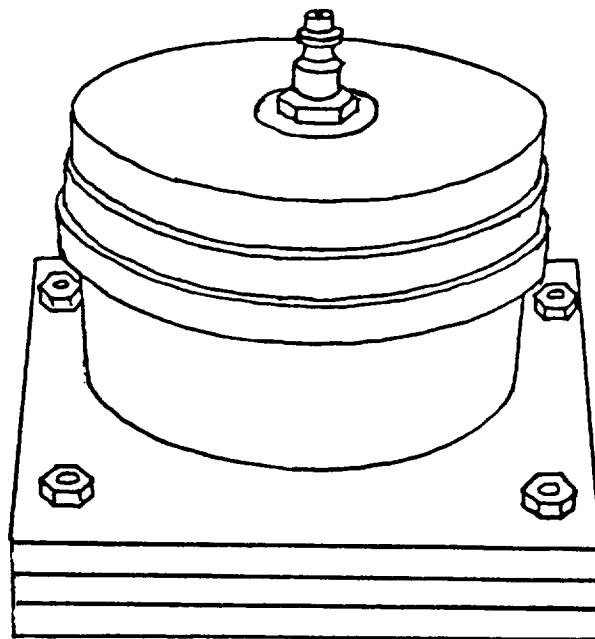
Figure 28

AIR PRESSURE

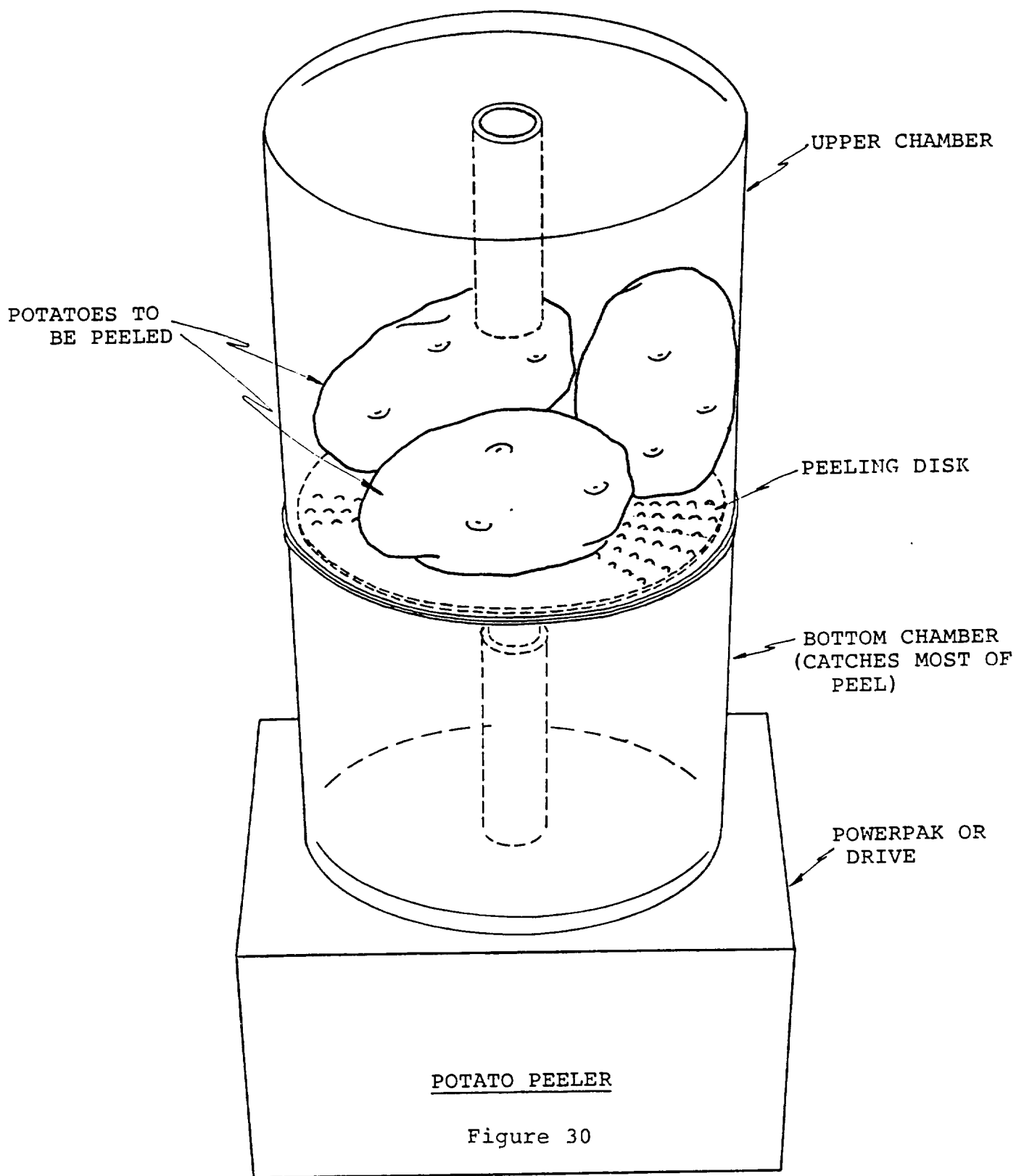


CROSS-SECTION OF PRESS-PEELING DEVICE

Figure 29



PRESS-PEELER
ASSEMBLY



to end up flat side down with the excessive removal of material, indicating the need to turn the potato whatever its shape. Subsequent trials with bars affixed to the periphery of the top chamber showed benefit for some shapes, but did not completely eliminate the problem.

As a next step, raised areas were attached to the disc as shown in Figures 31, 32, and 33 to force the object being peeled to rise and tumble. The results showed that the addition of the bumps was very effective, regardless of the presence of peripheral bars. Tests on round, conical and cylindrically shaped potatoes showed almost equally effective tumbling motion. Figures 34 and 35 show the effectiveness of the prototype on potatoes and sweet potatoes.

The last series of tests entailed extending the lower bowl rather than inverting another bowl. The center post of the inverted bowl appeared to cause undue obstruction, especially with larger potatoes. To prevent potatoes jumping out, the standard Cuisinart top was placed over the extension cylinder.

The single vertical ridge that had been used in the previous experiment was retained. Its height was approximately 2 mm. It was planned to increase the three raised areas on the cutting disc, but this proved to be unnecessary.

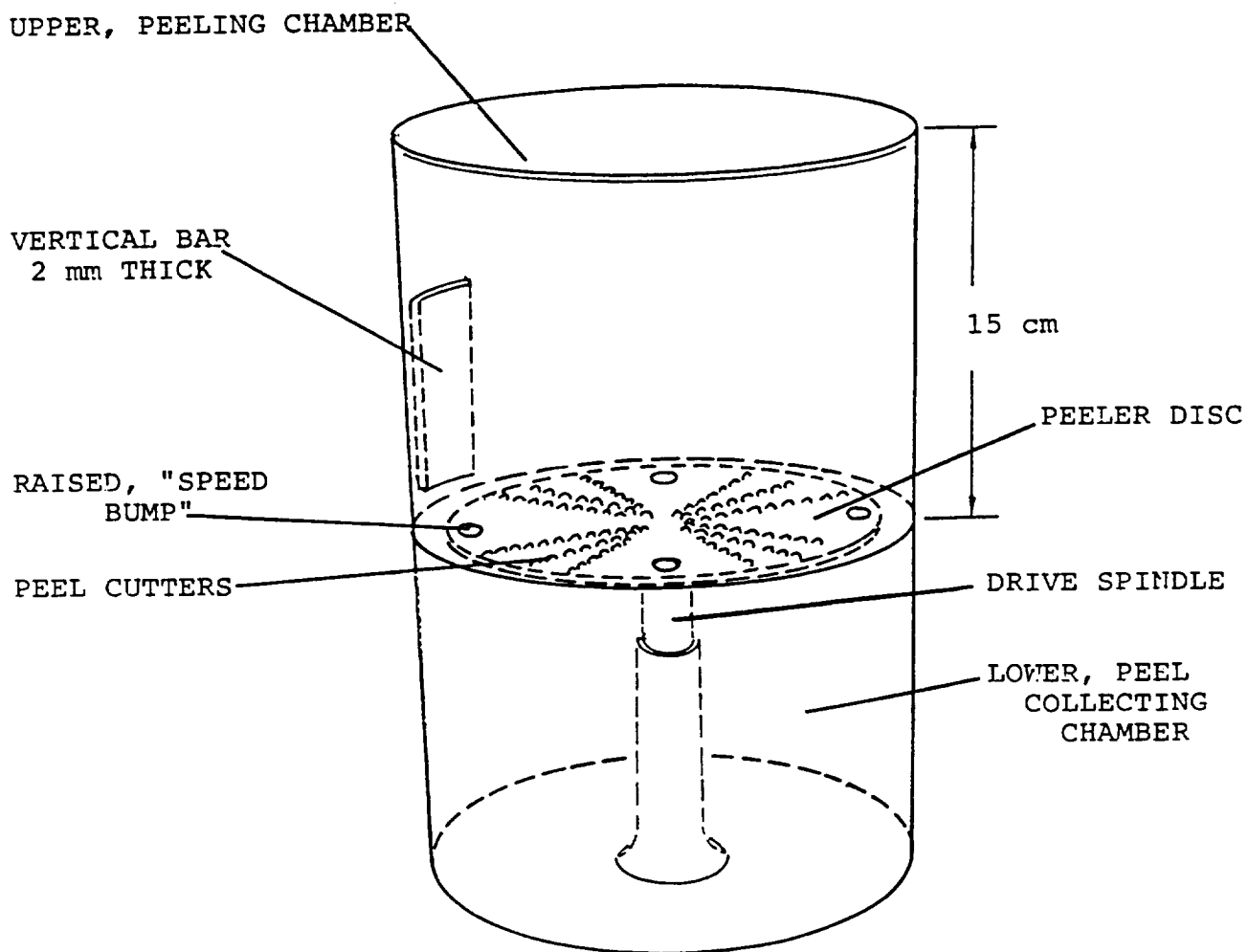
OBSERVATIONS:

1. Raised Areas

Potatoes are thrown with considerable force against the top. (In one photograph of a test, a potato is missing because it was ejected from the top.) This is particularly true for smaller tubers, and at the beginning of a cycle. Being tougher than the inside, the skin appears to offer sufficient resistance to the grating blades, so more of the disc rotational energy is transferred initially until most of the skin has been abraded. It is difficult to conclude whether the raised areas on the cutting disc are still necessary. At the beginning of a cycle, it is clearly the blades that transfer energy to the potatoes. However, as the softer central tissue becomes exposed, the raised areas may assume more significance in ensuring that the potatoes continue to tumble continuously.

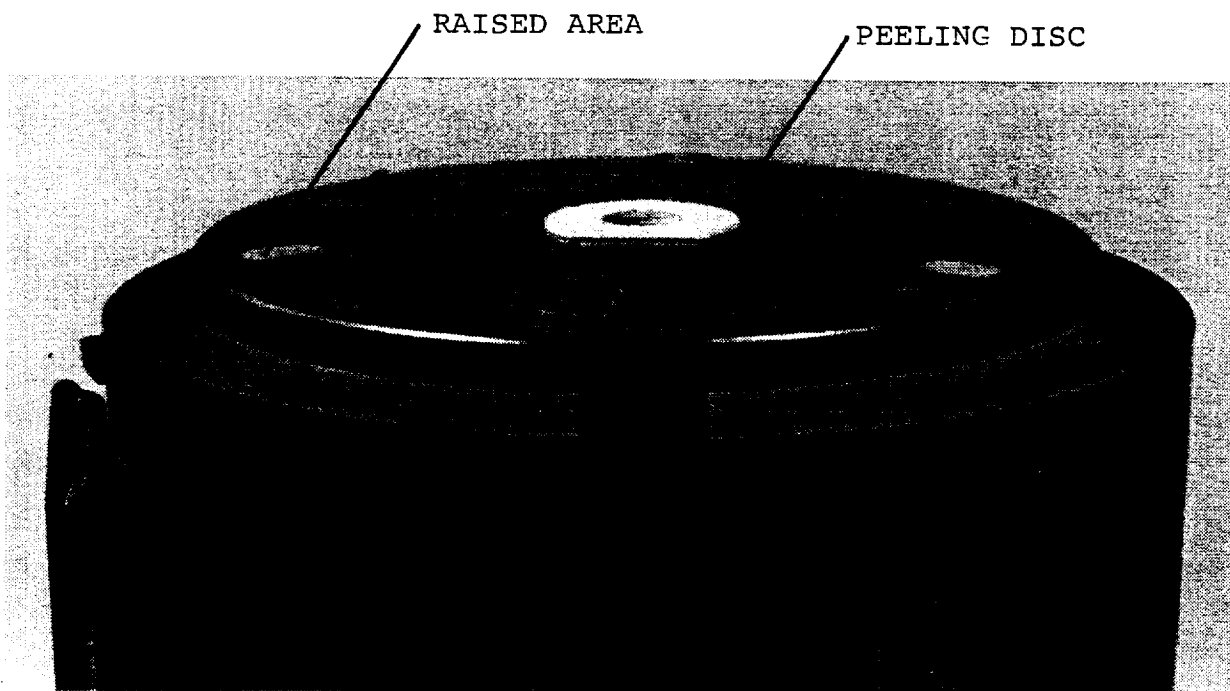
2. Zero Gravity

In zero-gravity, a 15° taper on the sides of the upper bowl (to form a truncated cone) will almost certainly ensure that potatoes are continuously redirected towards the cutter by a vector of the imparted centrifugal motion as they are by gravity with the present arrangement. When multiple potatoes are peeled simultaneously and their tendency to bounce while skin is still present is reduced, they then form an orderly moving ring of disorderly tumbling units between the periphery of the cutter and the cylinder wall, spilling over the vertical ridge. Our conclusion is that operation in zero gravity would actually provide even better results. The behavior of a single



MODIFIED POTATO PEELER CONCEPT

Figure 31



LOWER CHAMBER AND PEELING DISC SHOWING RAISED AREAS

UPPER CHAMBER REMOVED TO SHOW POTATOES AFTER 30 SEC. PEELING

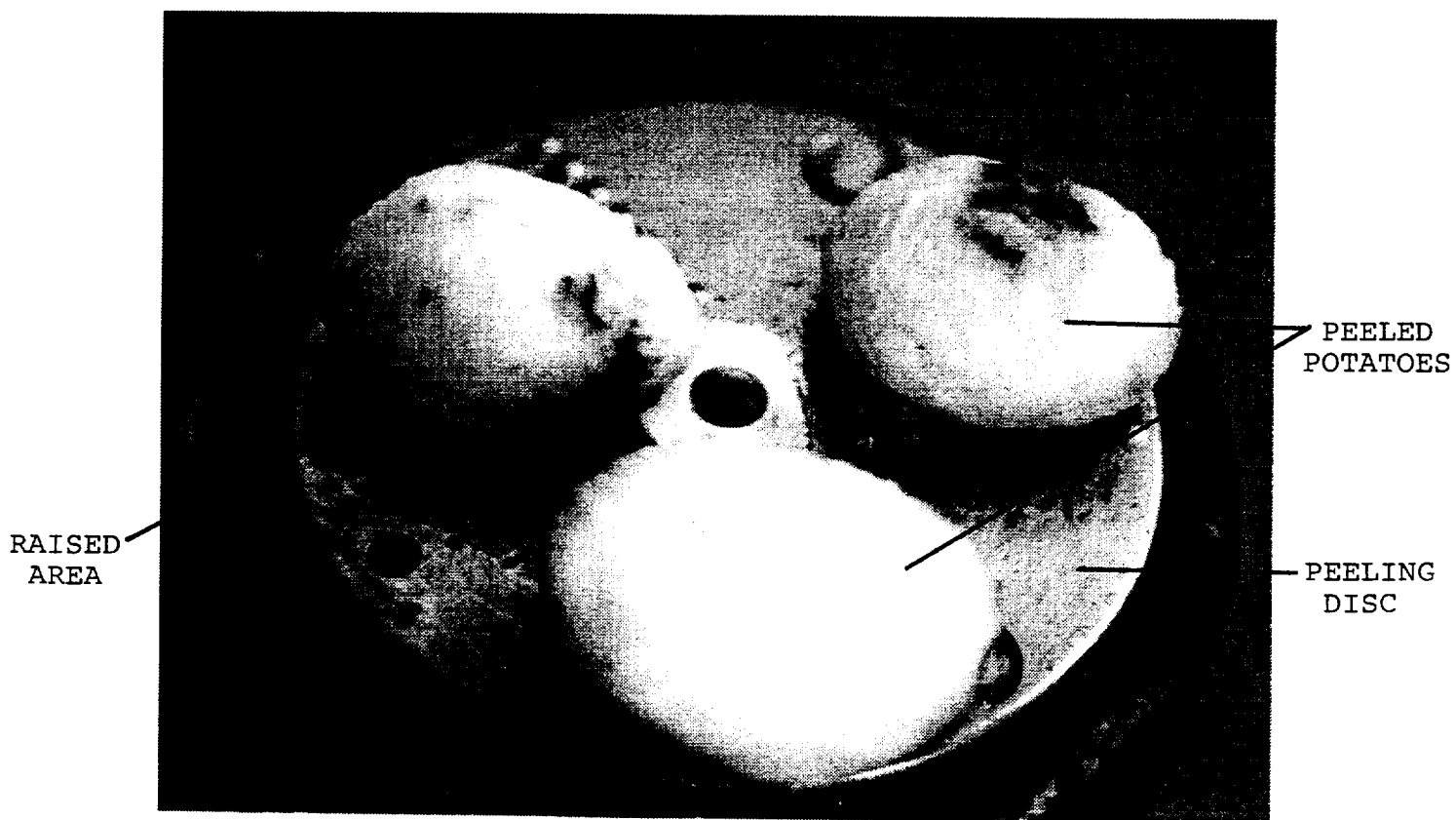
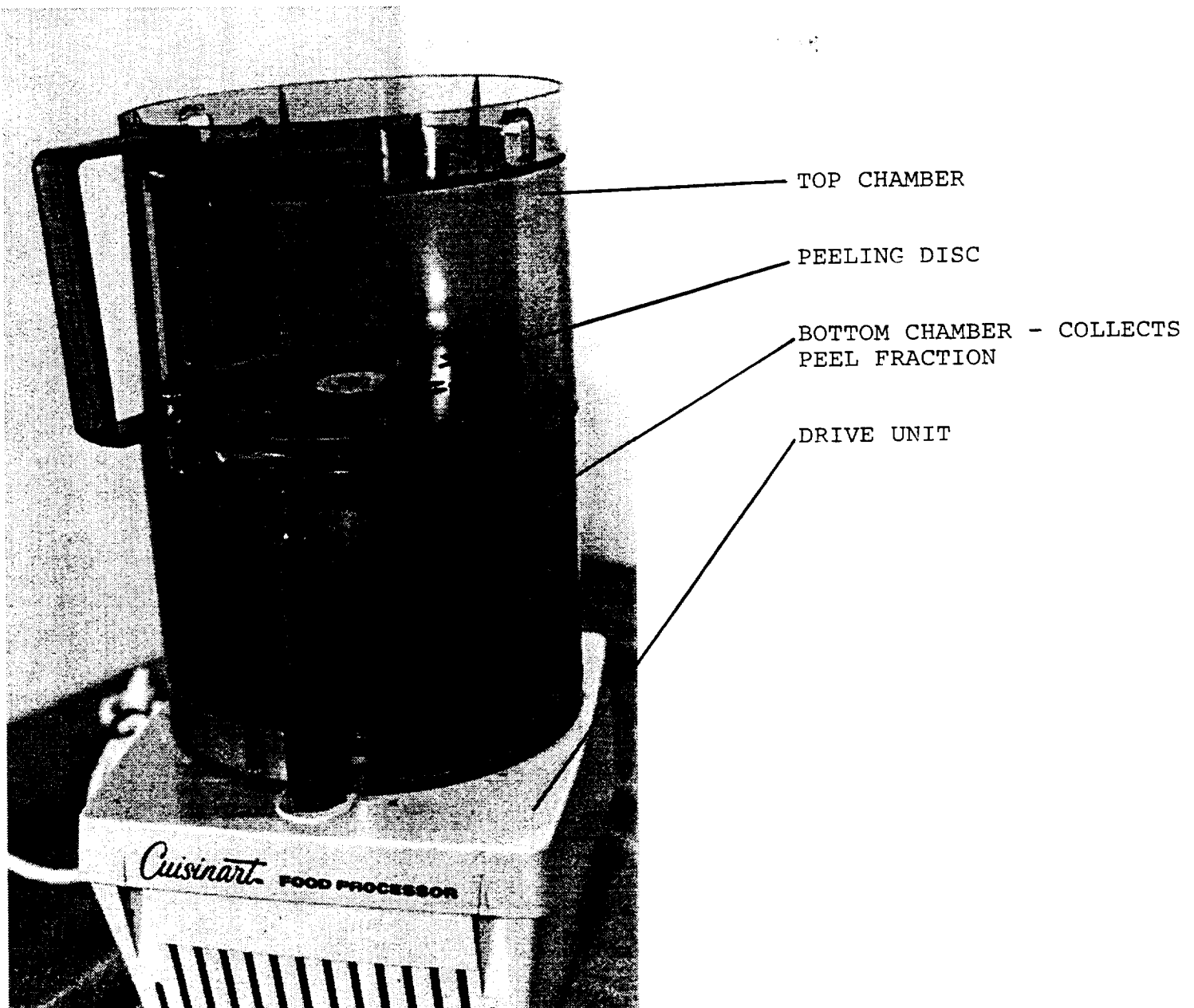
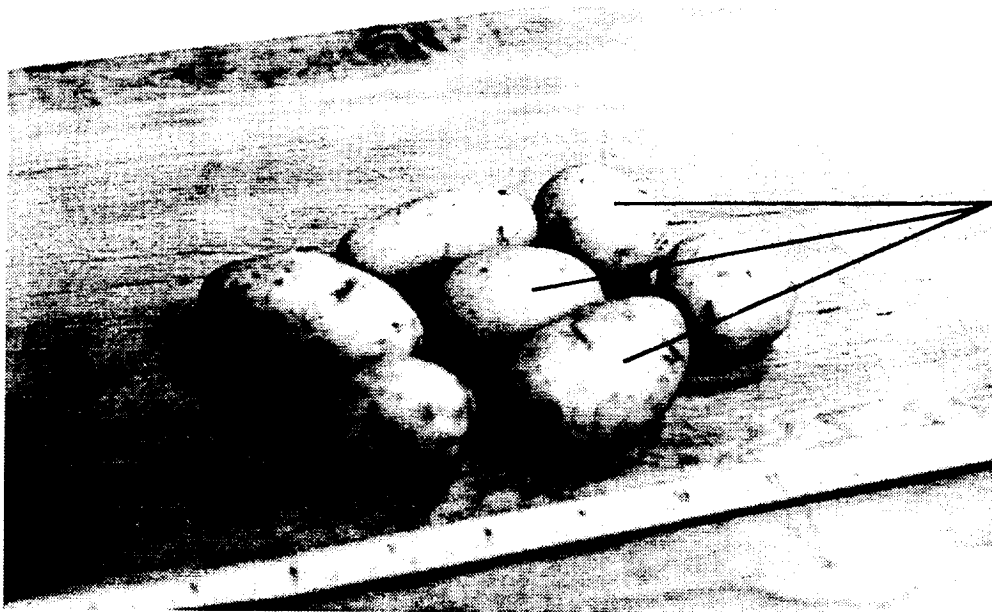


Figure 32

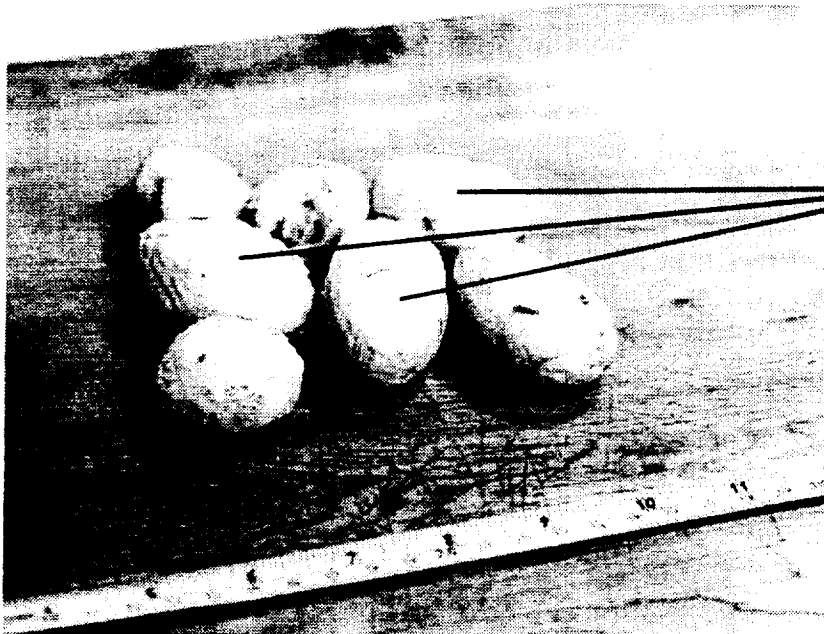


PROTOTYPE DISC TYPE POTATO PEELER

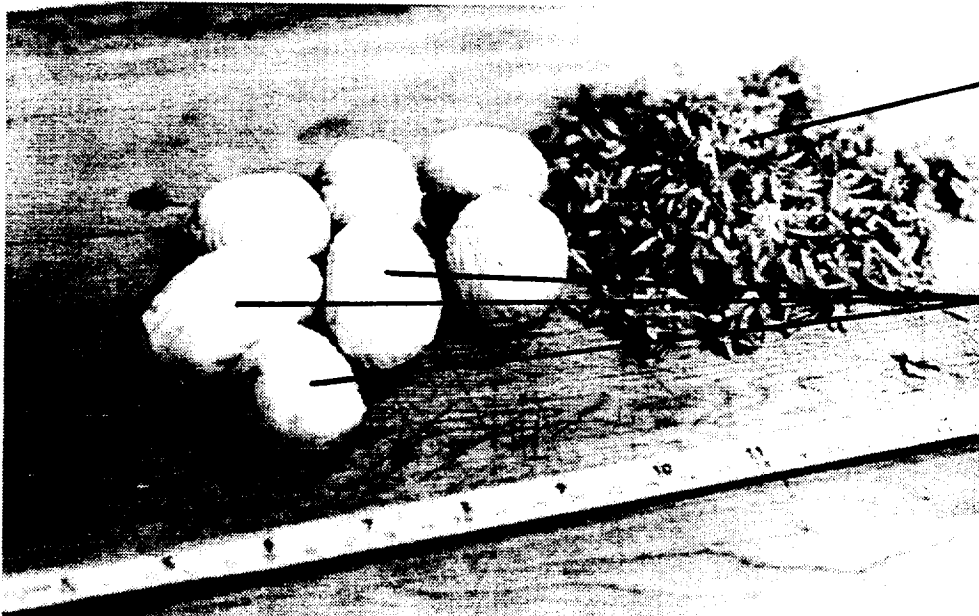
Figure 33



MULTIPLE SMALL
WHITE POTATOES
READY FOR PEELING



SMALL WHITE POTATOES
AFTER 30 SEC.
PEELING



PEEL RESIDUE

SMALL WHITE POTATOES
AFTER 60 SEC.
PEELING

Figure 34

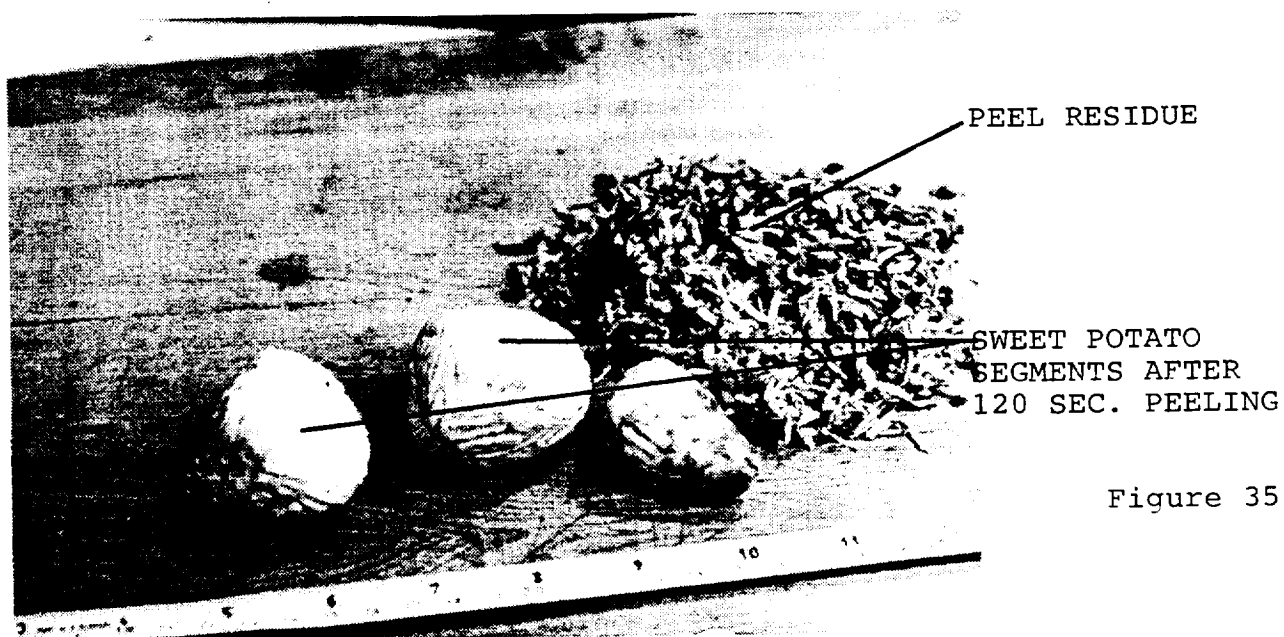
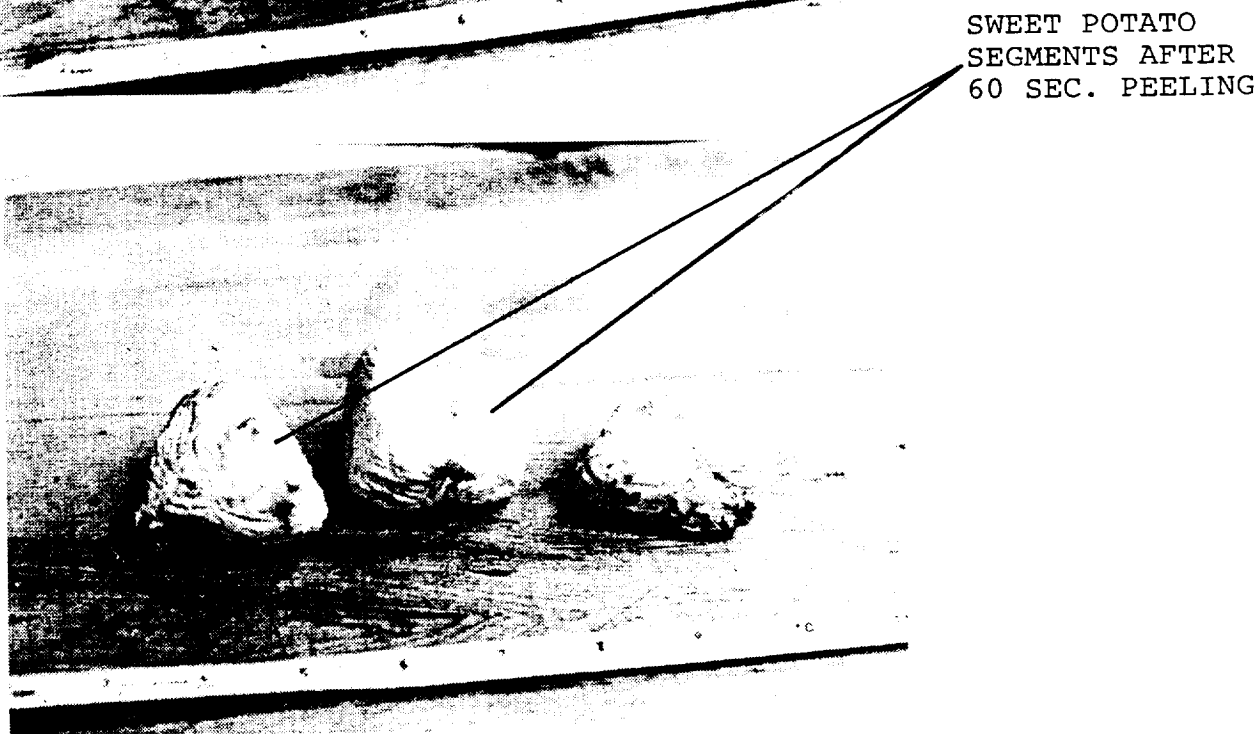
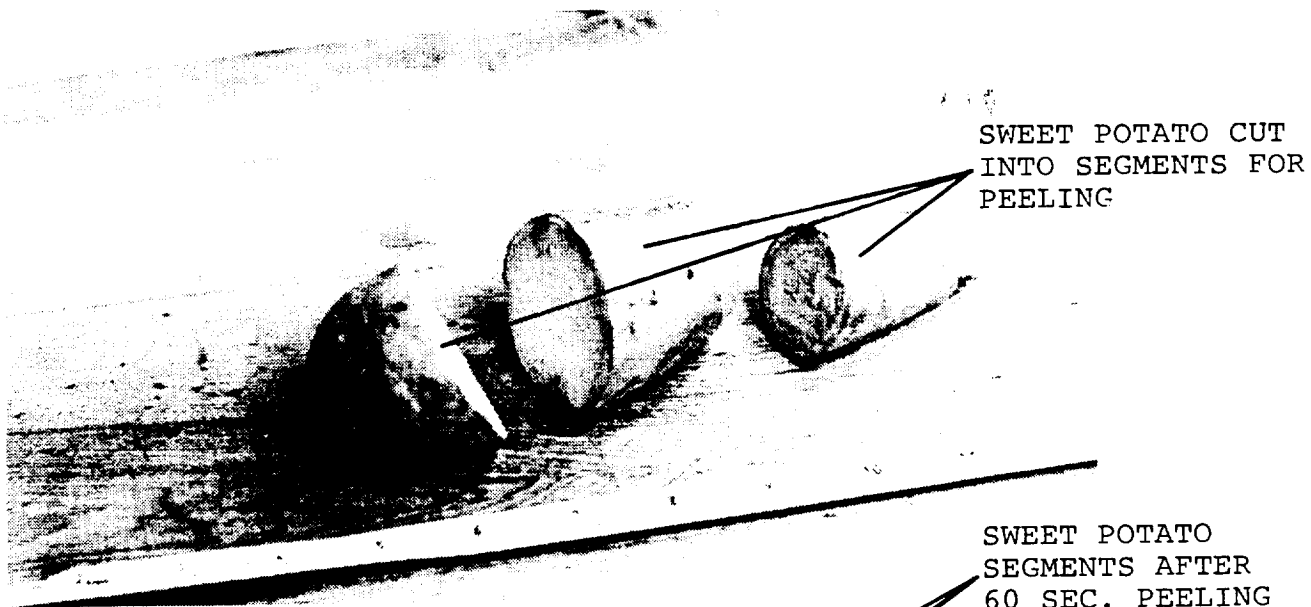


Figure 35

potato is likely to be similar to the progress of a ball in a pin-ball game -- periods of languid motion with no resistance interrupted by sequences of energetic ricochets.

3. Texture

Ordinary potatoes peeled faster than sweet potatoes, in about one minute compared with two. This would be expected, given the more leathery texture and lower moisture content of sweet potatoes. What may seem surprising is that larger potatoes peeled faster than smaller ones. This is probably because when the cutters are no longer razor-sharp, the smaller potatoes have less inertia than the large ones to keep them positioned for a complete cut and spend more time being bounced around than being in contact with the cutters.

4. Peelings

The peelings shown in the pictures were removed from the bowl with a spatula. No free moisture was present although squeezing them released copious amounts. They formed easily into patties. To cook them, some egg was mixed in as a binder to prevent their disintegration in a frying pan. They had a pleasant taste, very much like hash browns; and may have tasted even better if a small quantity of oil were used instead of egg and the cooking was done in a Jetstream-type oven.

5. Cleanup

Other than removing the peelings with a spatula between tests, no attempt was made to clean the equipment. At the conclusion of the tests, it was only necessary to wipe the cylinder with a paper towel and to rinse the cutter.

CONCLUSIONS

As a potato peeler, the system works very satisfactorily:

- No water is required during operation
- It handles a wide range of sizes and textures
- There is very little waste
- There is no free moisture to contend with
- In a CELSS environment the peel material may be eaten
- It can be easily adapted for in-situ cleaning using a spray of water and air to aspirate the waste
- It is quick
- The concept may be patentable

DRYER/THRESHER

A dryer and thresher are grouped together because as various designs were considered, it became apparent that the two functions might be combined. Although most of the experimentation has occurred with wheat, the equipment may also perform satisfactorily for soy. At the time the design evolved to this point, green soy beans were no longer available and FASI was

unable to evaluate the performance of the dryer/thresher design for soy beans.

DRYER

Dryers will be required for grains, beans, and gluten, proofing baked goods, drying pasta, and perhaps even for drying clothes. Grains and wheat will be harvested at the mature-green stage, and will need to be dried to withstand threshing, storage, and milling. Various cabinet-type dryer configurations were considered initially, but there was a preference for a continuous-type dryer. Usually they have better heat transfer, and continuous product handling promised to be easier than batch handling that would be required for cabinet dryers.

A suitable dryer design was a Jetstream-type dryer whose configuration had evolved from air conveyors of the slotted deck type used to convey light materials such as filled cereal boxes. The Jetstream design uses a slotted cylinder as a drying chamber. Drying air is introduced into the chamber around the entire cylindrical surface. The air has a tangential motion imparted by the shape of the slots.

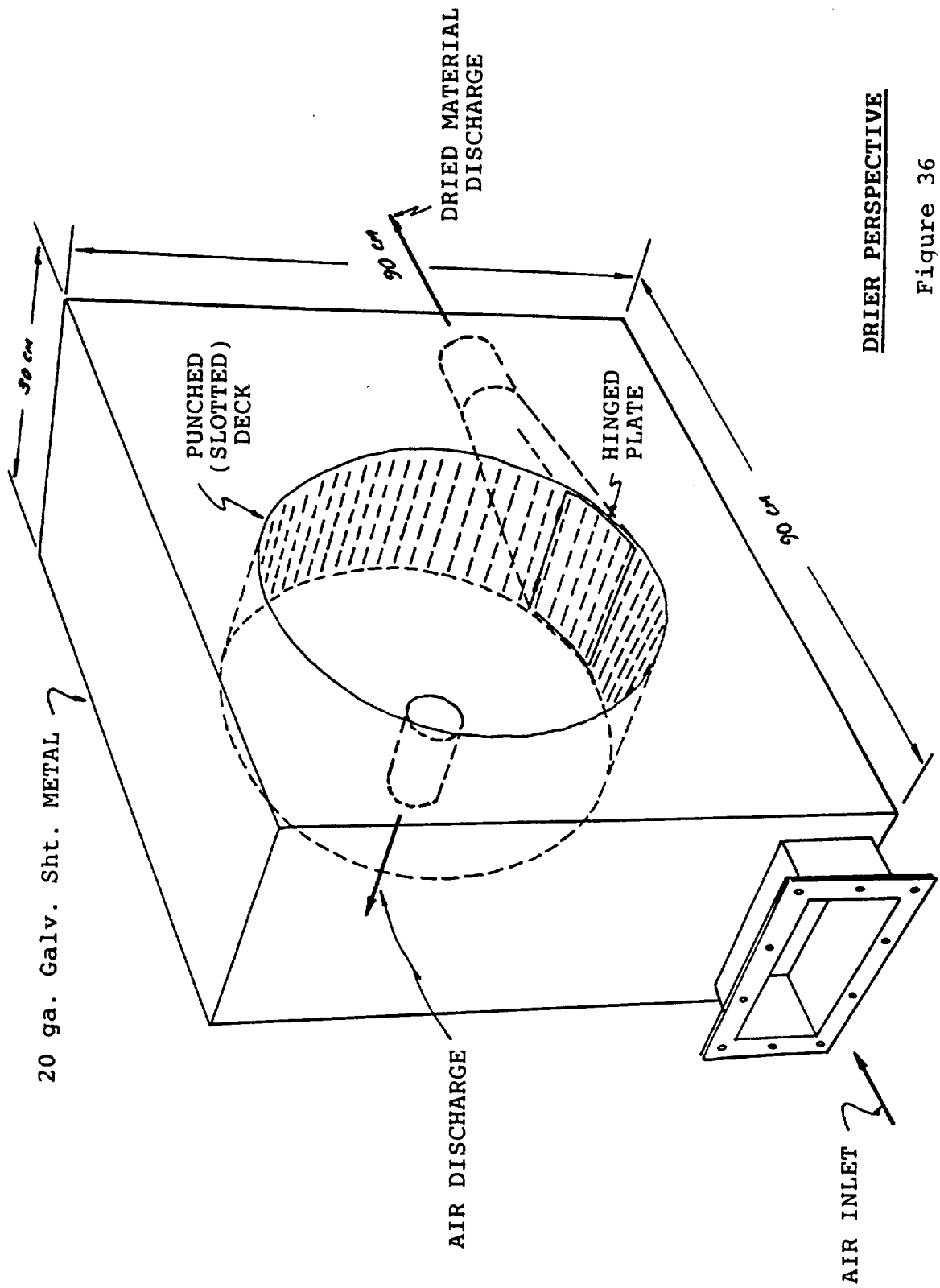
The idea of a circumferential air stream has some distinct advantages as follows:

1. The airstream contacts all the material to be dried uniformly, and because the air tumbles the material, drying is more efficient than in a system where the drying air approaches from only one direction.
2. The air stream induces a centrifugal force on the material being dried by imparting a circumferential motion. Material tends to concentrate at the periphery where it is easier to control, facilitating automatic discharging in batch operation.
3. The heavier, wetter material tends, because of its greater mass to collect nearest the cylindrical wall where it has the greatest contact with the hot dry air. This effect would be even more pronounced in zero-/micro-gravity.

Figure 36 shows a perspective of the initial dryer configuration.

AIR INLET

A flange is provided to connect with the blower. Air enters the box and is forced through the slots in the cylindrical punched deck. The tangential direction of the air entering the chamber is a function of slot geometry, with the overall product-carrying capacity of the system being a combination of that and air flow.



DRIER PERSPECTIVE

Figure 36

AIR OUTLET

The chamber behaves like the upper portion of a cyclone. Fines exit the chamber with the exhaust air through the pipe stub, but heavier material is retained within the chamber by centrifugal force.

PRODUCT INLET

Material to be dried is introduced as a batch through the front door or, with the blower off, through the exhaust port.

PRODUCT OUTLET_

The outlet is like a trap-door in the punched deck cylinder. When it is opened, centrifugal force combined with the air stream (which will preferentially seek the product outlet pipe) will rapidly empty the chamber of material.

AIR FLOW

Where punched decks are used as horizontal air conveyors, an air pressure of a few centimeters of water is sufficient to convey light materials like cereal boxes. In this demonstration (at 1 G), there has to be sufficient pressure to also lift the material from the bottom to the top of the cylinder, with the required pressure depending on the surface to volume ratio of the material as well as its density. The initial selection of a blower was unsatisfactory, having insufficient pressure. A one horsepower high pressure blower delivering 1,000 cubic meters per hour at 10 cm pressure was ultimately selected. Figure 37 shows the dryer air circulation loop.

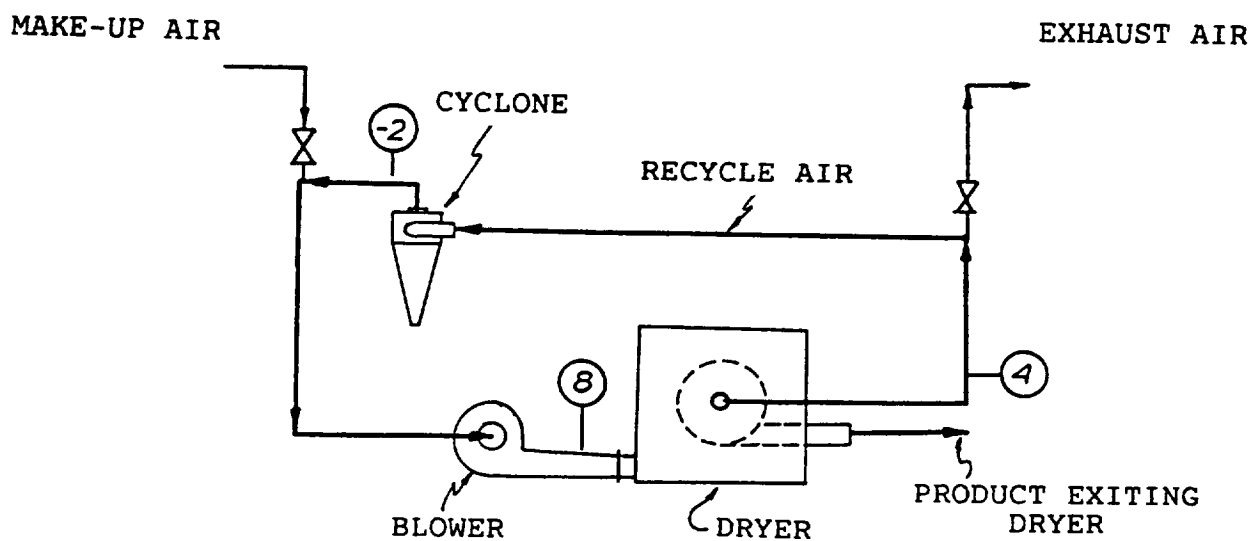
DECK CHARACTERISTICS

The slots in the air-conveying deck proved inadequate; they provided insufficient lift and had too much dead space at the edges of the deck, so a louvered deck was substituted (Figure 38). With this design change, the air flow was satisfactory for the unit to function as a dryer, although its capacity at 1 G was limited to about 200 gm of wheat berries.

At this point, the potential of the unit as a thresher was recognized, so before further description of the unit's performance as a dryer is offered, the evolution of a wheat thresher will be described.

WHEAT THRESHER

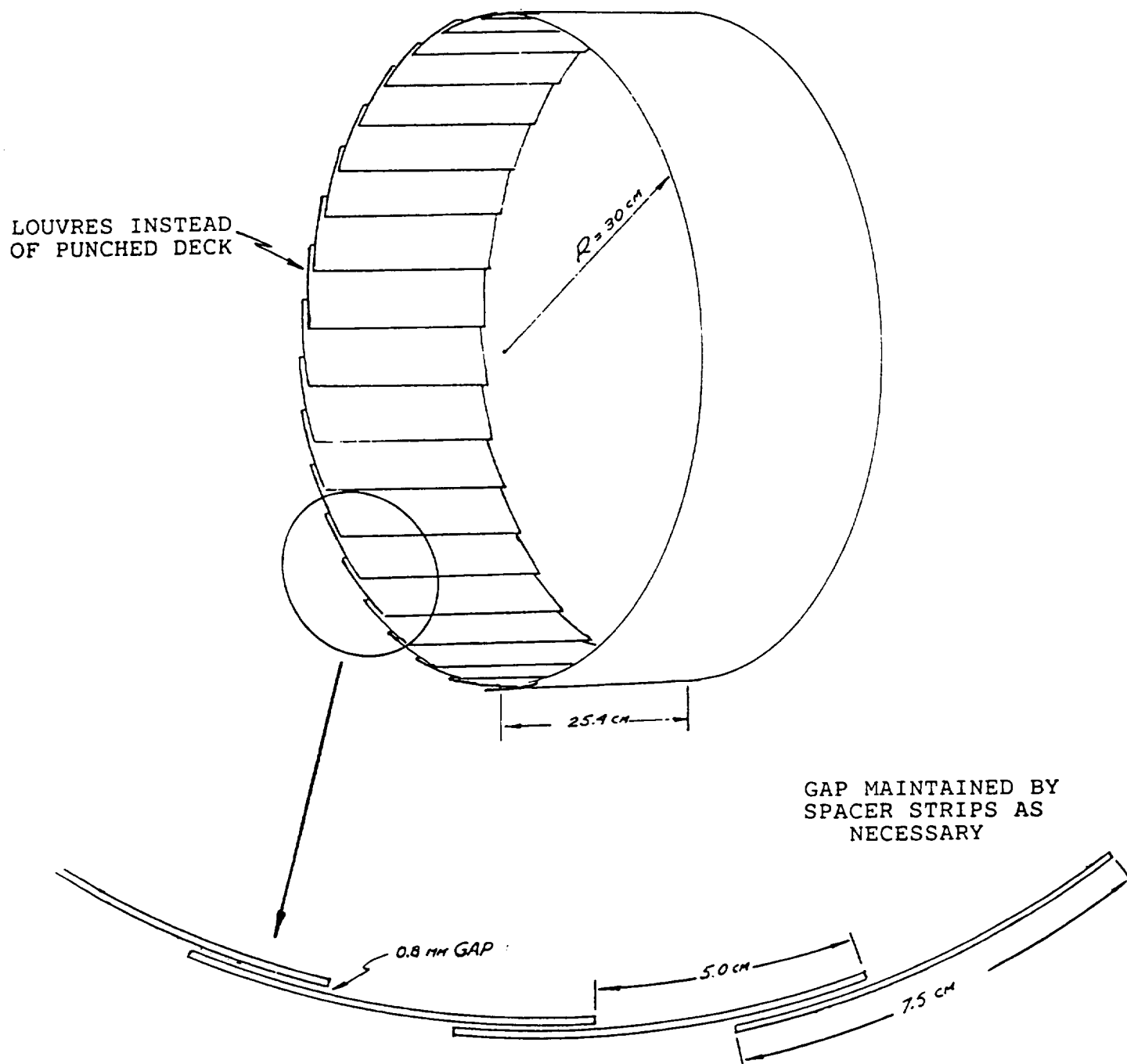
Combine harvesters are typical wheat threshers. The thresher unit consists of a rotating cylinder and a series of bars that partially envelop the cylinder. Optimum cylinder rotational speed and the clearances between drum and bars have evolved from



○ — TYPICAL PRESSURES (cm., Hg)

DRYER AIR CIRCULATION LOOP

Figure 37



MODIFIED DECK FOR JETSTREAM-TYPE DRYER

Figure 38

1820 but with the basic principles of operation unchanged. With slight differences in clearance, the design could work for wheat and soy beans. Unfortunately, the design does not lend itself to small scale operation. Even laboratory-type units are trailer-mounted and have 10 horsepower engines.

Various designs relying on impact to separate wheat berries from chaff were considered, but the first concept to be tested by building a model used a different principle. It consisted of spring-steel tines radially mounted on a rotatable shaft positioned inside, and coaxially with a screen cylinder (Figure 39). The design was based on the idea, initially tried manually, that the spring steel tines would disrupt the wheat heads and pods to break loose the berries and push them through the screen (with the help of aspiration).

The screen on the prototype was 6.35 mm mesh rather than 4 - 4.5 mm mesh that would have been preferred but which was not readily available. As a result, an excessive amount of chaff was pushed through the screen along with the berries. Nonetheless, with fully dried wheatberries, the concept worked on a prototype scale.

A development of that concept is shown in Figures 40a and b. It offered the potential of being versatile enough to handle wheat and soy without changing screens. A prototype was built and tested. It worked well in that it provided almost complete threshing for both wheat and soy. However the biggest drawback was that there was a high potential of damage to wheat berries and soy beans, particularly if they were to be harvested at a mature green stage and only partially dried, so that concept wasn't developed further.

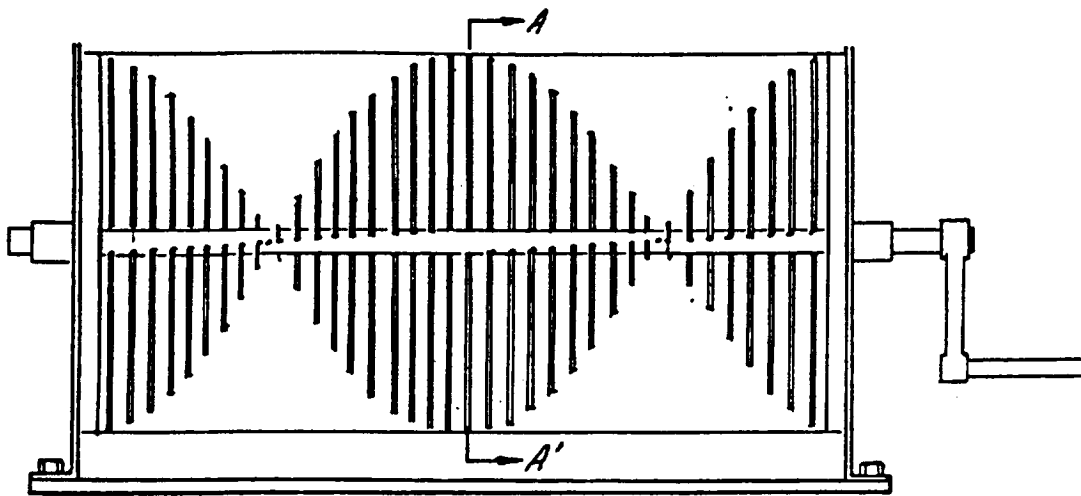
COMBINATION DRYER/THRESHER

In the early tests with wheat berries, half a dozen whole wheat heads were introduced into the dryer chamber in which two small anvils had been placed at the bottom of the dryer where the velocity of objects would be the greatest. The heads were threshed in about 10 minutes.

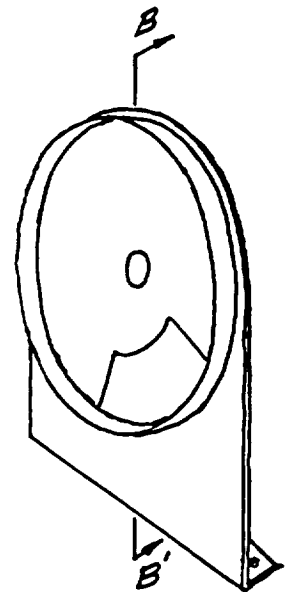
The next series of tests was conducted to refine wheat threshing and determine whether some separation of wheat from chaff were also possible.

For threshing, breaker blades were reshaped to give a backward incline of 30°. In earlier tests, heads of wheat bridged vertical blades and lodged there until eventually beaten off by the impact of chaff, berries, and other wheat heads. Four pairs of blades were inserted initially, but reduced to two in a staggered arrangement.

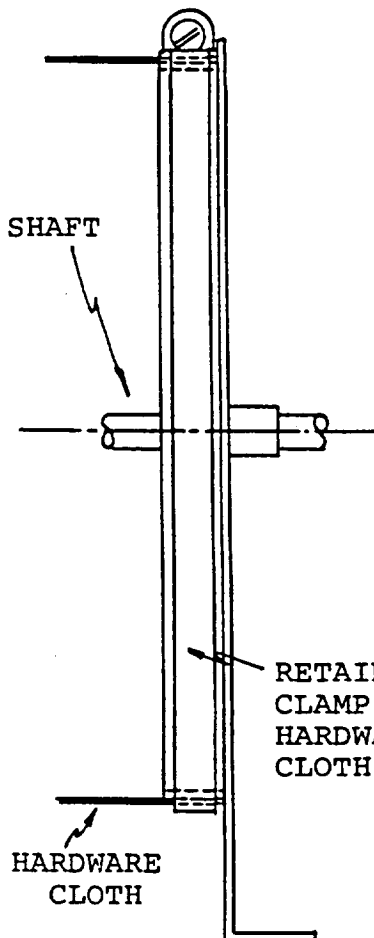
The louver covering the product exit port (which has not been used) was raised to ensure an air flow from what was previously a dead spot.



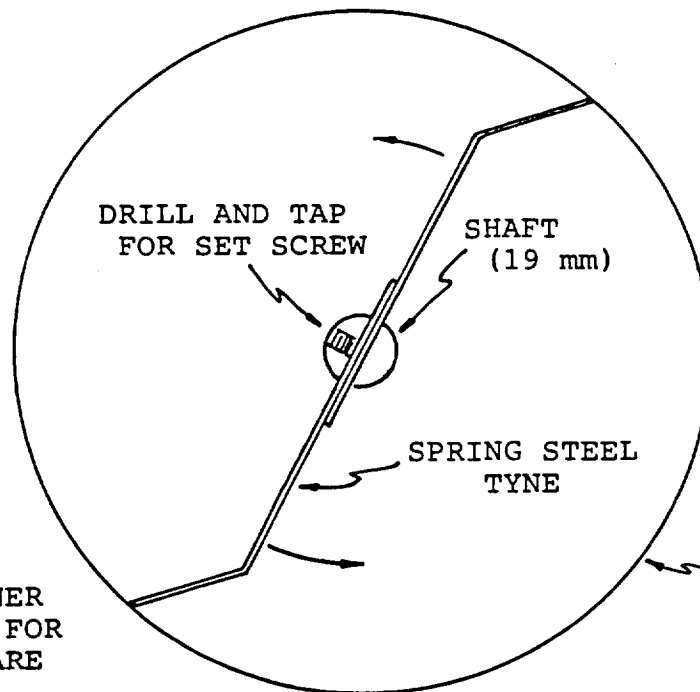
SIDE VIEW - PROTOTYPE THRESHER



END PLATE



END PLATE
CROSS-SECTION



CROSS-SECTION A-A'

PROTOTYPE THRESHER

Figure 39

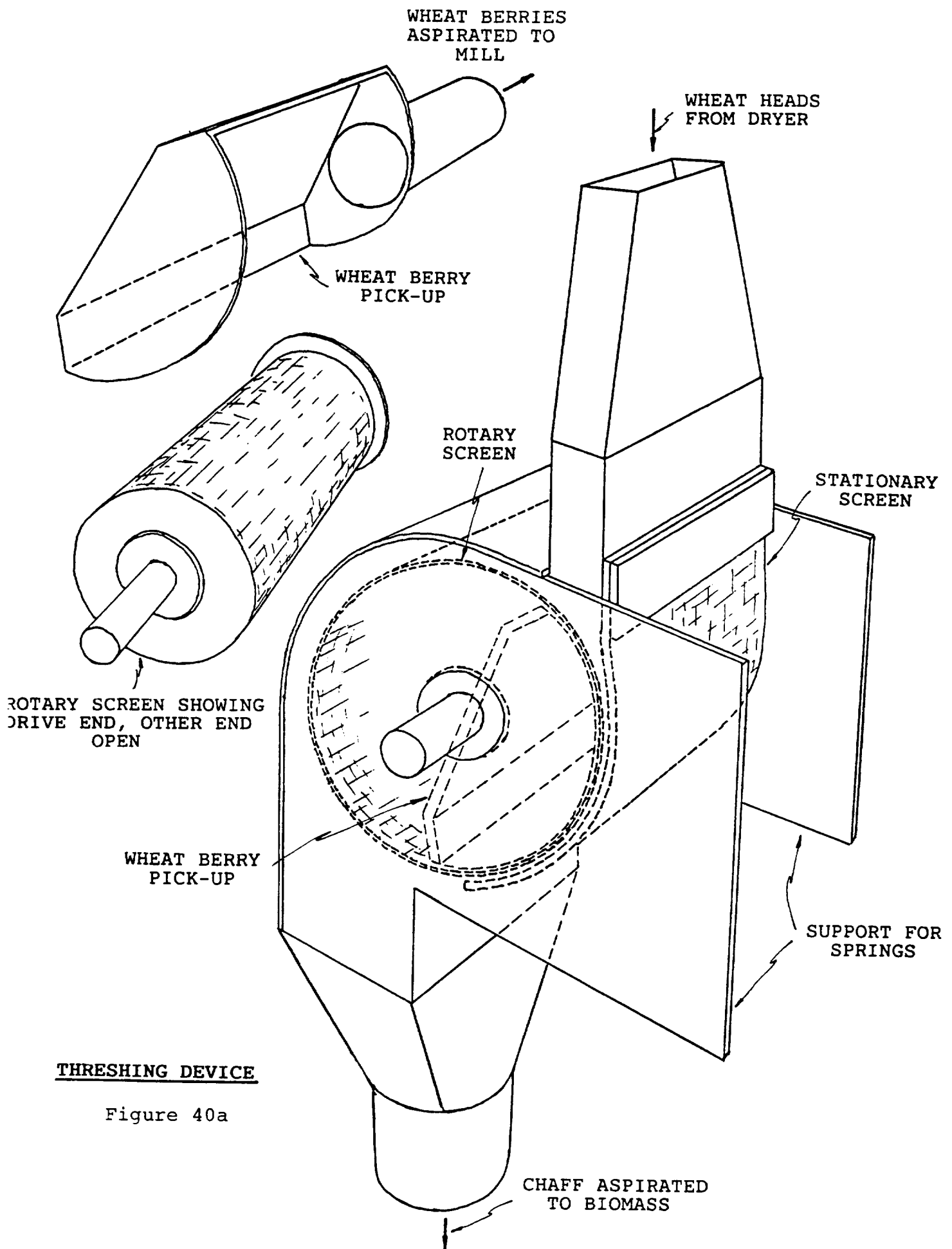
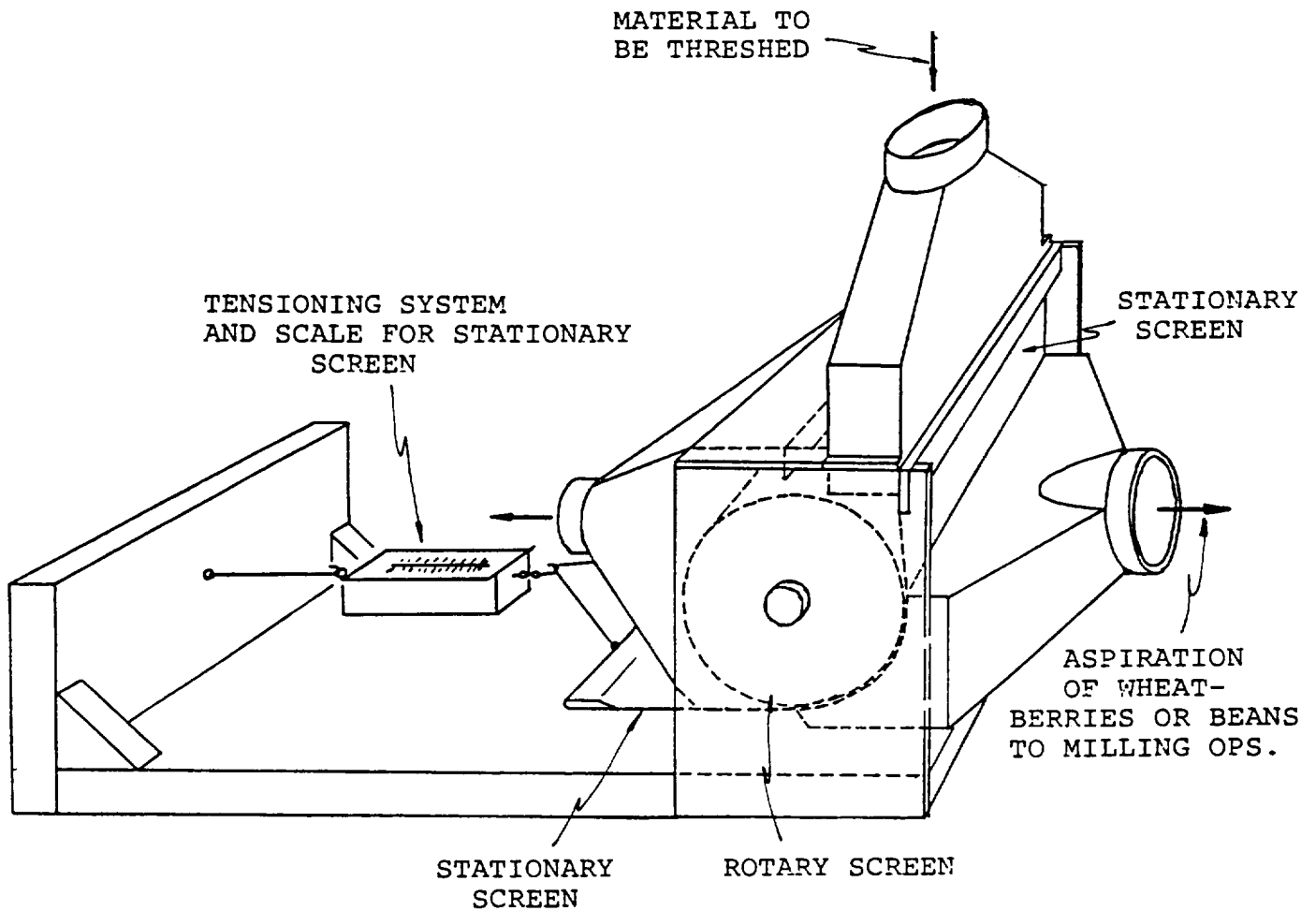
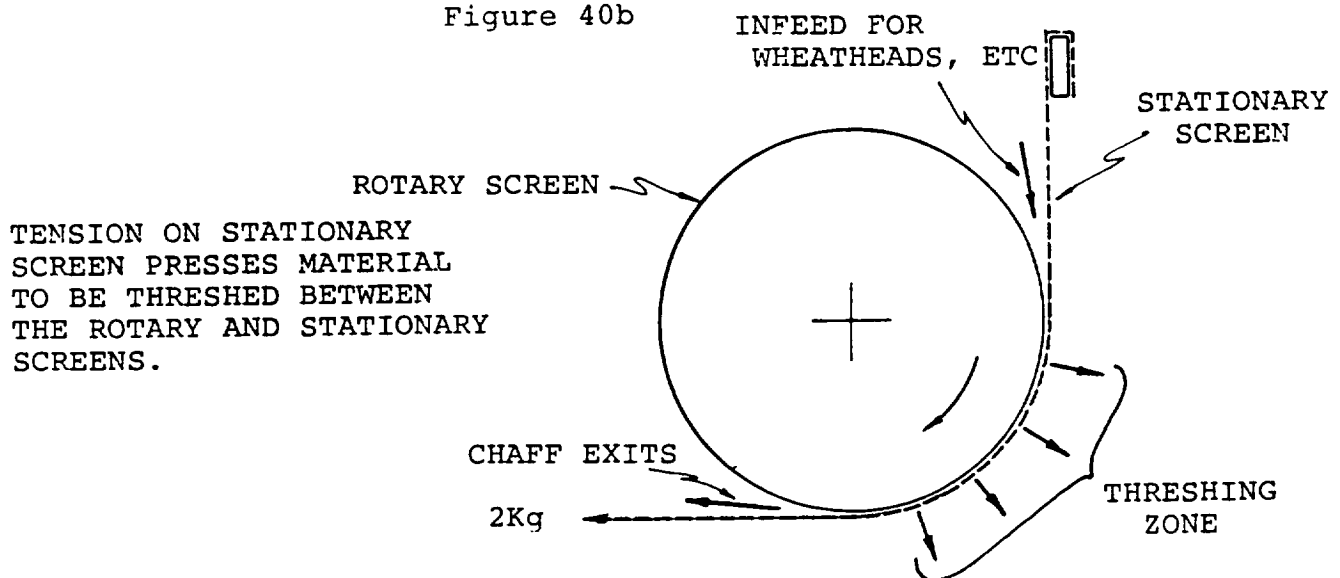


Figure 40a



THRESHING DEVICE

Figure 40b



The entire periphery of the louvers had 45° miters formed at the transitions to the radial walls. There is a dead spot at these areas where there are 2 cm wide spacers to provide the air slots and to hold the whole louver assembly together. The miters were formed with spackling paste.

For separation, an adjustable disc was added. It was connected to a 10 cm diameter pipe fitted in the exit port so as to be able to slide in and out (Figures 41 and 42). Spoilers were glued to the face opposite the exit port. The intent was to be able to adjust the disc by moving the assembly from the back position (Figure 41) to the front position (Figure 42) so that as the gap between the disc and the front face diminished, the radial velocity of the inward flowing air would increase. At some point, the force of the radial air flow would overcome the force imparted by the centrifugal flow, and separation should occur. The spoilers were intended to break the centrifugal flow of the air as it was forced to the exit port so that, once captured at the edge of the disc, separated material would not be flung out again.

OBSERVATIONS

Threshing

1. Effect of surface

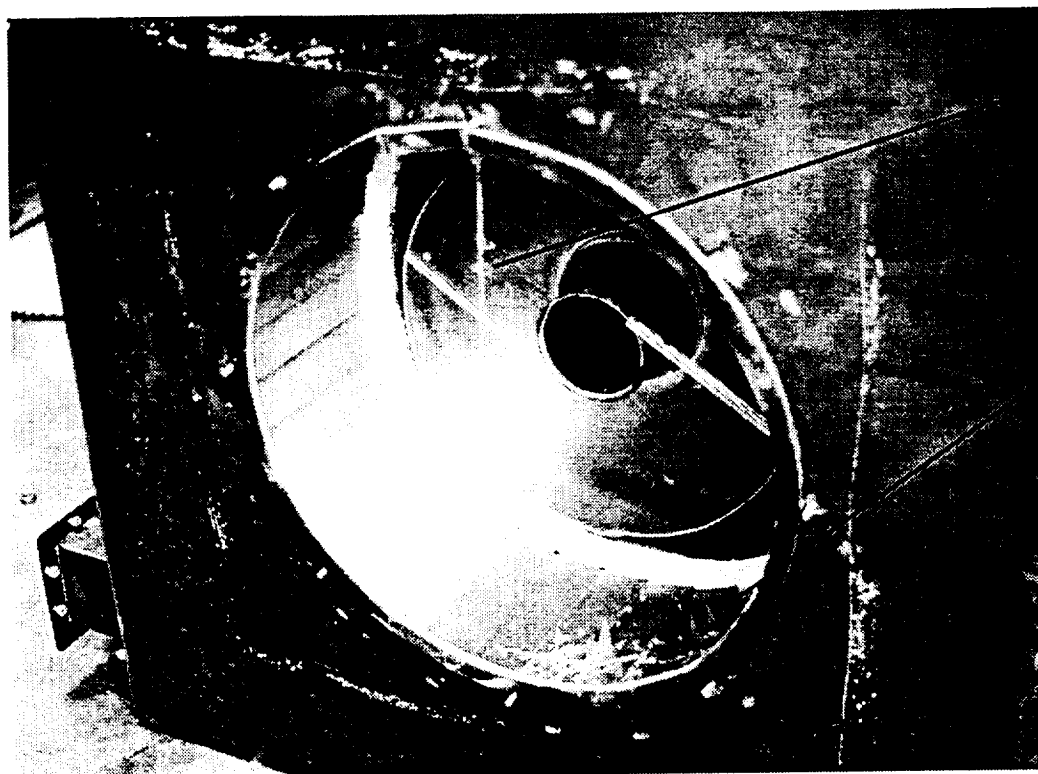
Twenty wheat heads were inserted with four pairs of blades. Most of the heads became stuck between the outer pairs and the walls. Evidently the spackle was not nearly smooth enough. The heads of wheat oriented themselves with the stalks facing the air stream and the tails dug into the spackling with the tenacity of Velcro. Two sets of blades were therefore removed, and the tests recommenced. Although much improved, some heads still clung to the wall long after others had been substantially threshed. Once the heads had been partially threshed, the clinging problem was no longer apparent. If the surface was completely smooth, threshing would most likely be accomplished sooner. To completely thresh all twenty heads took 45 minutes.

2. Effect of Backward Slope of Blades

The 4 cm height of the blades appeared ideal, as did the slope. Heads would impact them, be held no more than a few seconds as they were driven by the circulating matter to the blade tips to break free into the airstream. The conditions in the dryer are such that the berries are easily separated from their husks, but it takes much longer to strip a head completely.

3. Flow

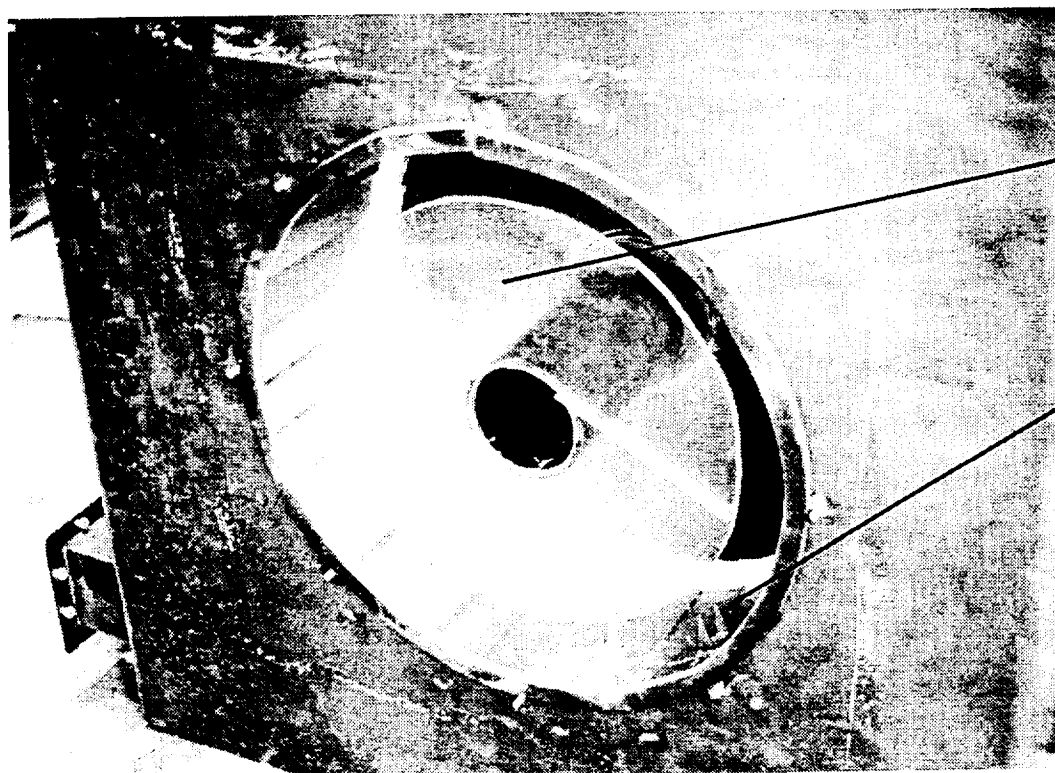
Material does not flow evenly as it would in a cyclone. Berries tend to bounce off the louvers and move in a square pattern around the periphery. Eliminating the previous dead spot improved the flow noticeably. The capacity was not tested, but with the present configuration would be limited



PLASTIC BAFFLE
RETRACTED

THRESHER ANVIL

Figure 41



PLASTIC BAFFLE
PARTIALLY
ADVANCED

THRESHER ANVIL

Figure 42

PROTOTYPE LOUVER DRYER MODIFIED FOR INVESTIGATION OF POSSIBLE USE
IN THRESHING AND CHAFF SEPARATION

to about 50 heads of wheat at one G. In zero gravity, the capacity may be four to five times greater. The heavier wheat berries would not bunch at about the four o'clock position in the dryer where their combined mass smothers the airflow through the adjacent louvers.

4. Separation

The disc offered a degree of separation. This was evident from a build-up of dust that was abraded from the spackle. The dust remained in the dryer until the disc was moved toward the front face, whereupon the dust vanished.

The separation was sufficient to give good separation of the berry husks, but the process was extremely slow. What happens with the broken heads is that they are drawn to the exit port, but wheat berries also hit the spoilers and ricochet across the port, getting drawn out of the dryer.

The last set of tests were undertaken to accelerate wheat threshing times and to thresh both dry and green soy beans. The essentially sharp, backward-sloped anvils used previously were replaced with blunt anvils. The intent was to provide a broader impact area (to accelerate threshing) and to limit the extent to which material got hung up on the knife edges. The selection of the earlier streamlined anvil design had been predicated on the assumption that the airflow should not be broken, otherwise the threshing velocity would be diminished. However, since air enters around the whole circumference of the dryer, any break in the flow should promptly be reestablished by the louvers behind the obstruction. This seemed to be the case, because there was no discernable difference in the apparent rotational velocity between the streamlined and blunt anvil profiles.

MODIFICATIONS

1. Anvil Bars

The streamlined anvil bars consisted of two pair of backward-sloped blades. They were spaced 2.5 cm apart, were 5 cm high, and had a rake of 30°. Two blunt bars replaced the two pair of sloped blades. They were 1.25 cm wide and 5 cm high oriented radially, one set 10 cm ahead of the other.

2. Outlet

The adjustable disc used to enhance separation in the previous experiments was removed.

WHEAT TRIALS

Forty heads of wheat weighing 50 gm were placed in the thresher. At the start, the bulk of them hung up on the sides with the steams facing the airstream and the ends digging into the spackle-filled miter. Once one or two heads broke free, they

quickly dislodged the others so that after 5 minutes, the entire mass was moving without hanging up. After 15 minutes, approximately 90% of the wheat was threshed. After 30 minutes, about 99% of it was threshed.

Threshing time was therefore improved by 100% over earlier tests. Not all the improvement may be attributable to the blunt anvil bars. In earlier tests, only about 1 gm of wheat was used (20 heads). It appears that with a larger quantity, a larger amount breaks free from the initial bundles that form, causing a faster break-up of static heads.

In zero gravity, the thresher should be even more efficient. With gravity, the mass of wheat berries collecting on the uphill section of the circumference eventually overwhelms the ability of the airstream to lift them over the apex of the louvered circumference, and the system essentially stalls. In zero gravity, there is theoretically no limit to the quantity that can be threshed. Bulk rather than mass will be the limiting constraint.

Our conclusion is that the louvered dryer will double as an excellent thresher for wheat.

DRY SOY BEAN TRIALS

The effect of the blunt bars was more marked with soy beans than with wheat. Harvested soy pods are often in clumps of four or five attached to one another at the stems. They are also partly split, if dry, and the split ends tend to be oriented downstream, making them particularly susceptible to catching on the knife-edge type anvil. The blunt anvil is too wide for this to happen. The result is that dry soy pods thresh very easily. It took only 5 minutes to completely thresh 50 gm.

GREEN SOY BEAN TRIALS

The dryer proved unsatisfactory in threshing green soy beans (Edamame)

The beans had been blanched and frozen. They also appeared to be a much larger type than the typical agricultural commodity. The pods were the size of those of large peas, and the beans only slightly smaller than lima beans. By way of contrast, the dried soy beans used were slightly smaller than mature peas.

The streamlined anvil bars were used with one placed at the bottom of the dryer and one upstream at about a 7 o'clock orientation towards the air flow.

The air flow was generally unable to levitate 6 or 7 beans placed in the dryer so that movement was haphazard. Sometimes not one of the beans was in motion and the dryer had to be agitated to get the beans moving again.

After about 10 minutes, only two of the pods had split open fully, with another pod half broken. The intact beans showed considerable bruising and would eventually have split. However, the beans that had been released were also severely bruised. The damage to the beans may have been exacerbated by the blanching.

It would be reasonable to conclude that with some pre-drying, green soy pods can be threshed satisfactorily with the dryer/thresher. How long it will take, and what the condition of the threshed beans will be though, is hard to predict.

ROLLER-THRESHING SYSTEM FOR GREEN SOYBEANS

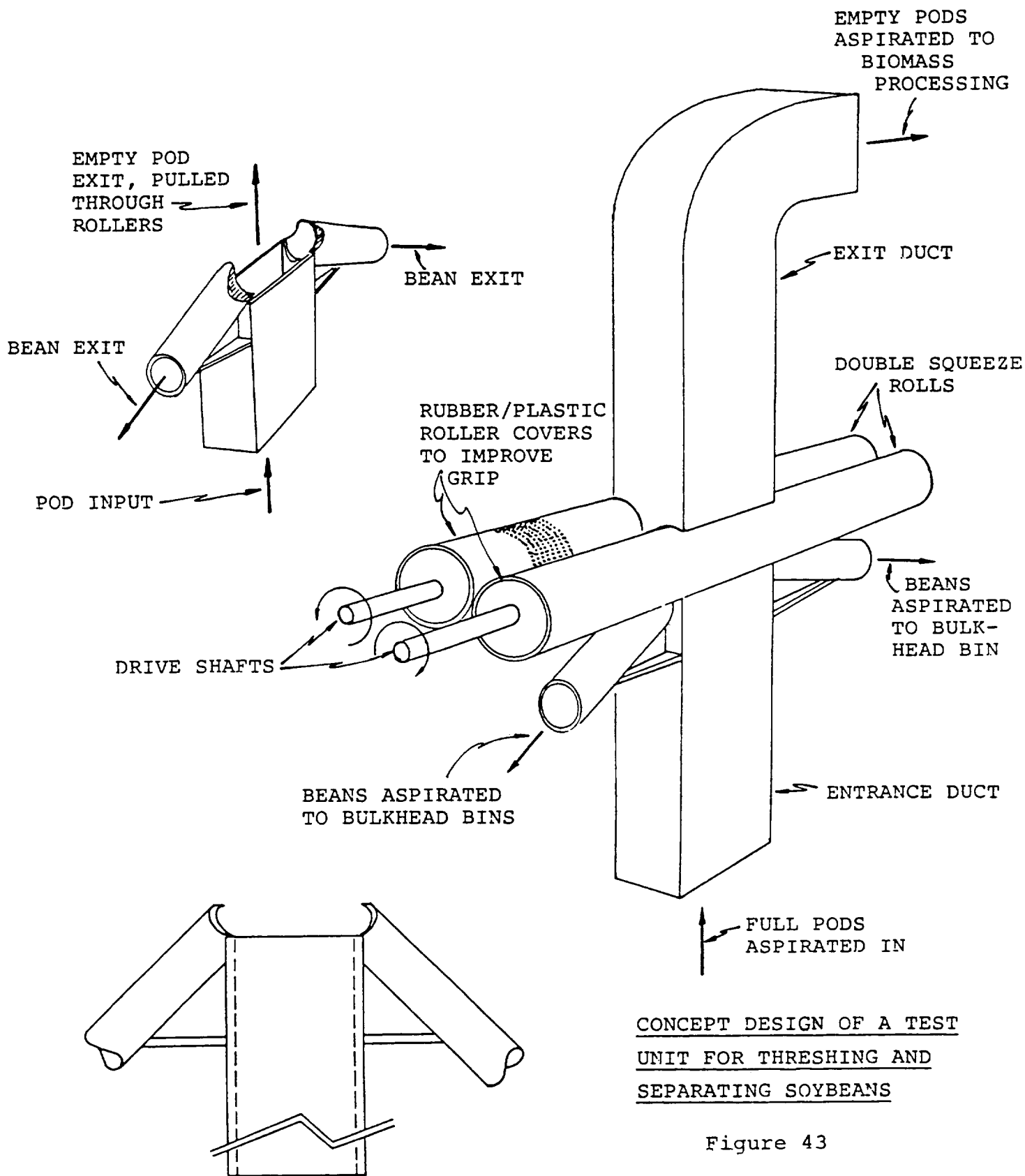
In the absence of samples of soybeans at the point of mature-green harvest, two types of threshers have been developed and tested on a prototype scale. The choice could depend on how dry and brittle the pods are at time of harvest, or whether the beans are to be consumed green or dried prior to use. Trials of a pneumatic/impact system built into the louver dryer and designed for use with comparatively dry pods, or soybeans that should be dried are described in the following section on the dryer. The following system was devised to thresh soybeans harvested when the pods are still soft and flexible, and when the beans are to be consumed green. This system was tried very briefly, but successfully on shell peas, and is based on a concept developed by Food and AgroSystems to process and clean, blanched almonds. It consists of pinch rolls set close enough together to grip and pull pods between the rolls, but too close to let the beans pass through. The prototype configuration and a photograph of the unit are shown in Figures 43 and 44.

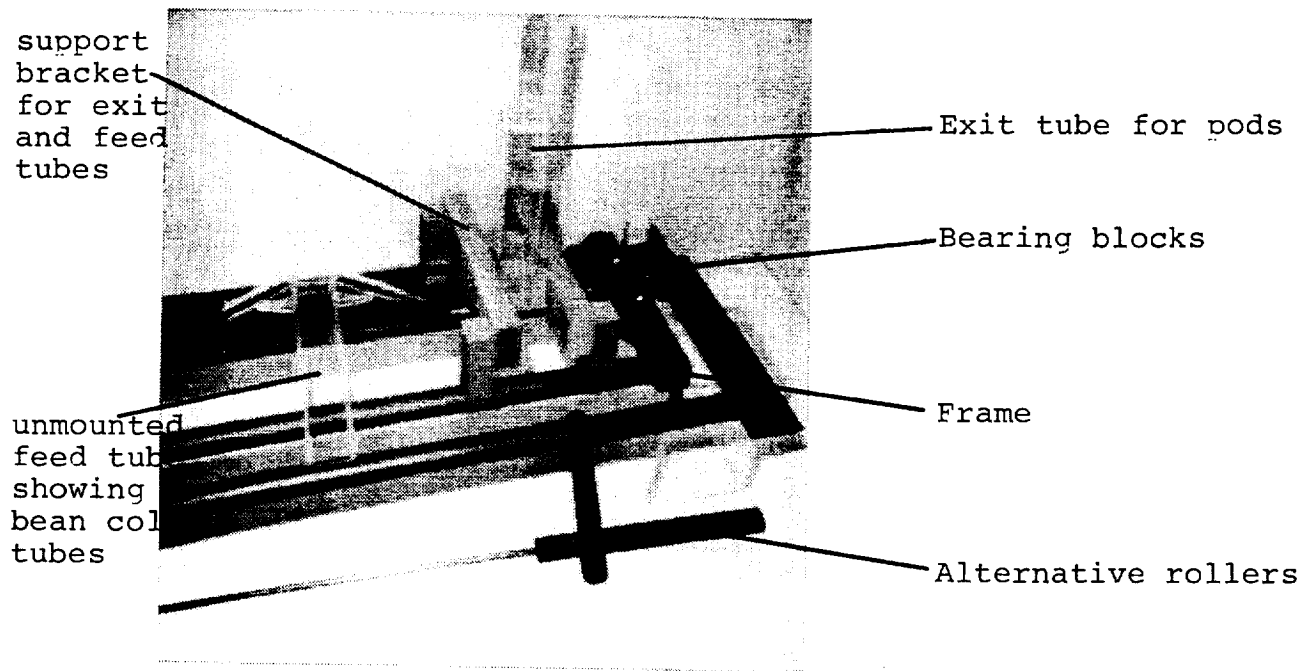
In the absence of mature-green soybeans to use in evaluating this unit, runs were made using edamame purchased locally.

Edamame are large seeded, green soybean pods and beans, commonly used as a green vegetable and a snack similar to peanuts in Asian countries. The pods were easily threshed by the prototype, however, the beans were too large (about the size of thick lima beans) to pass through the bean collection tubes. Commercial edamame threshers use a single roll mounted above a conveyor also using a pinching action to remove beans from the pods. Based on the results of the prototype trials with shell peas and edamame, the double-pinch roll with aspiration is a technically feasible approach to threshing mature-green soy pods in a zero-gravity environment. Some adjustment may be necessary to the diameter of the bean collection tubes depending on the bean size of the soy cultivars selected. Currently, the tubes used in the prototype are .95 cm I.D., adequate for the standard, small seeded varieties, currently being studied. Unlike the edamame cultivars, these varieties are not usually eaten green.

WASH/DEWATERER

Since little "dirt" will exist in the CELSS environment due to

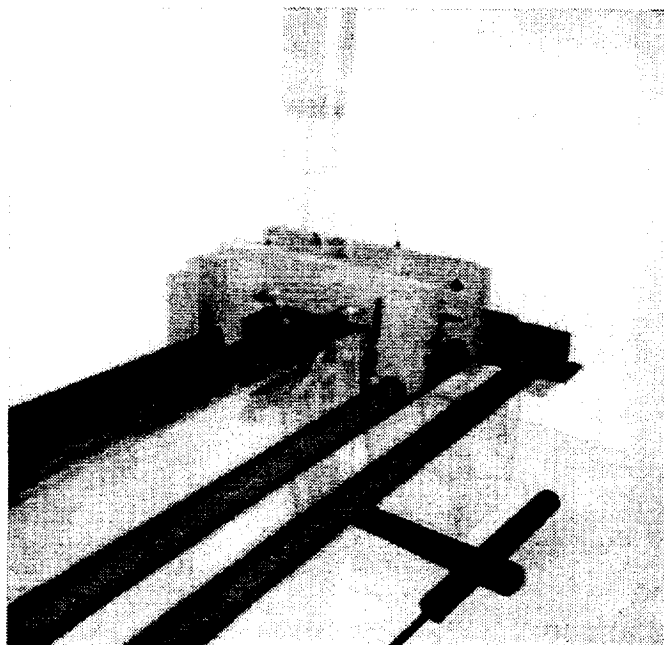




1.6 cm diam. Ryertex rolls

PROTOTYPE PINCH-ROLL THRESHING DEVICE

Figure 44



aeroponic or hydroponic culture, only a minimum of washing, essentially a water rinse, will be required. In the case of potatoes and sweet potatoes the purpose would be to remove nutrient solution residues; however, it might be beneficially used also in the case of salad greens to "freshen" and crisp them. In either case a batch process is visualized where only that amount of ingredients needed for the next meal would be washed and dried. Based on this rationale, a small centrifugal spinning device is seen as the most practical and efficient solution.

The conventional salad spinner, with some adaptation or modification, was seen as an potentially ideal solution to this task. In a CELSS, the unit shown in Figure 45 would be powered by a bench-mounted power-pak. Other connections to the unit would include "quick-connects" for cold water and air which would be injected into the spinner by a spray nozzle built into the lid. Cold water would be sprayed on the produce as it is spun at moderate speed. The lid would be locked to the canister to prevent any produce from escaping. In addition a vacuum line would be attached to the canister to efficiently aspirate away any water removed by the spinning process. To facilitate this aspiration, a series of vent holes would penetrate the lid, but be covered by flapper valves that would allow air in, yet prevent water overspray from getting out. Once the canister was loaded and the lid attached, the process would begin: starting with spin cycle, activating the vacuum, and then starting the water spray. In the case of potatoes and sweet potatoes, a warm air spray would be provided as the water spray cycle finished its cycle.

Several simple salad spinners were evaluated as candidates for a prototype with little difference noted. A simple hand-crank unit was selected and purchased for testing, and modified as described. Difficulty was encountered in fastening the exit port to the plastic bowl of the spinner. An adhesive could not be found that would produce a seal as well as a mechanical bond that would stand the handling associated with the experiment. As a result, it was decided that a mechanical attachment in addition to a silicone seal would be used. A flange was bonded to the acrylic tube using a high strength cement that was suited to the materials. This connection was successful. A hole pattern was transferred from the flange to the bowl and a riveted connection made. A silicone sealant/adhesive was used to provide a gasket at the joint. Figure 46 shows the finished prototype spinner.

A tentative run was attempted with the spinner in this configuration, using wet lettuce leaves and a 1 1/2 HP Shopvac as a vacuum source. The test failed due to the flexibility of the basket and bowl. The vacuum was far too strong and the entire apparatus was deformed to the point that the basket would not rotate. This was not totally unexpected. Several equally-spaced holes were drilled in the cover near the perimeter as shown in Figure 47. These holes performed two functions. They allowed a balancing air flow into the apparatus and by positioning them near the perimeter, the air flow forced water

Greens DeWatering

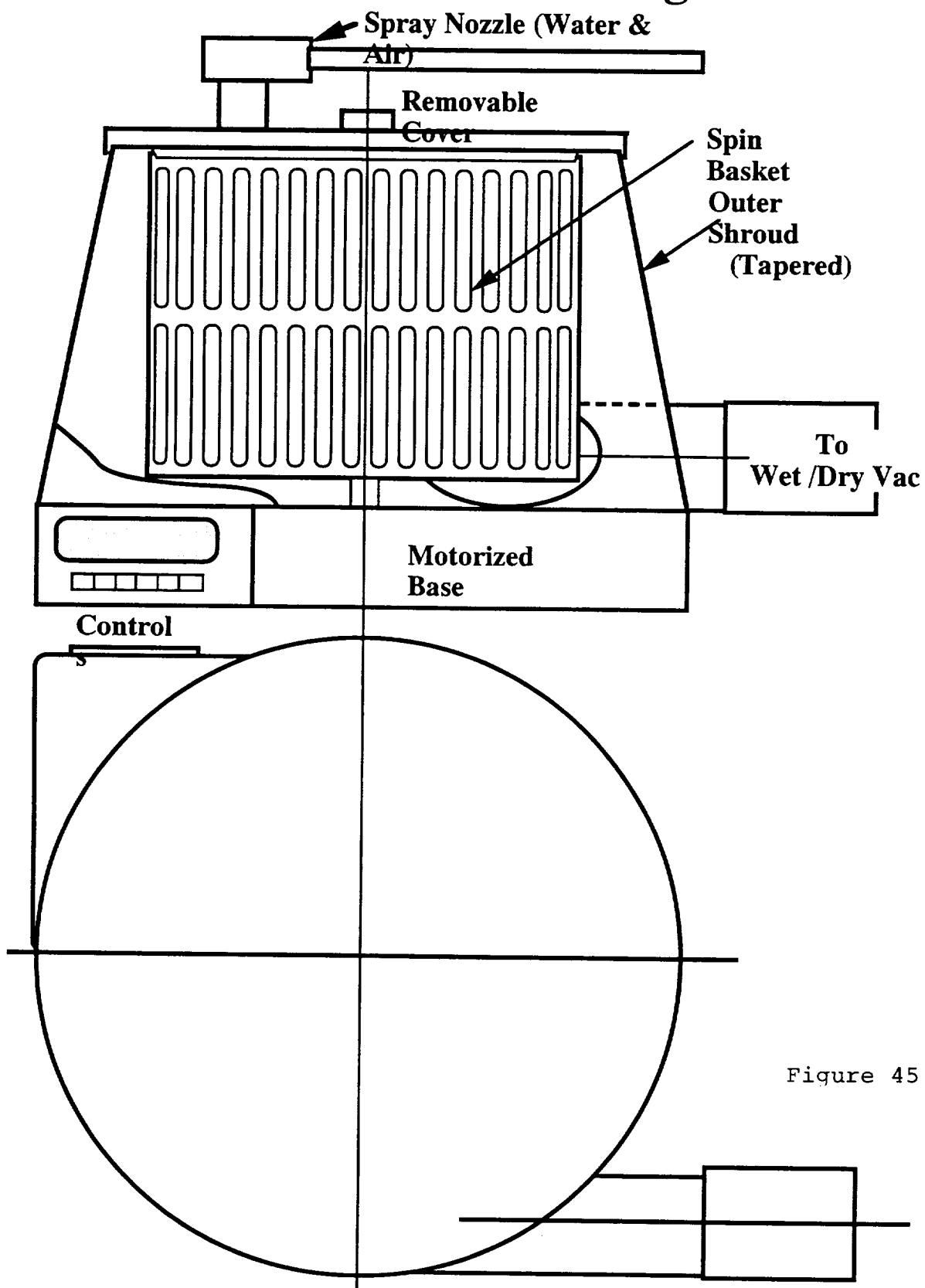


Figure 45

PROTOTYPE DEWATERING DEVICE

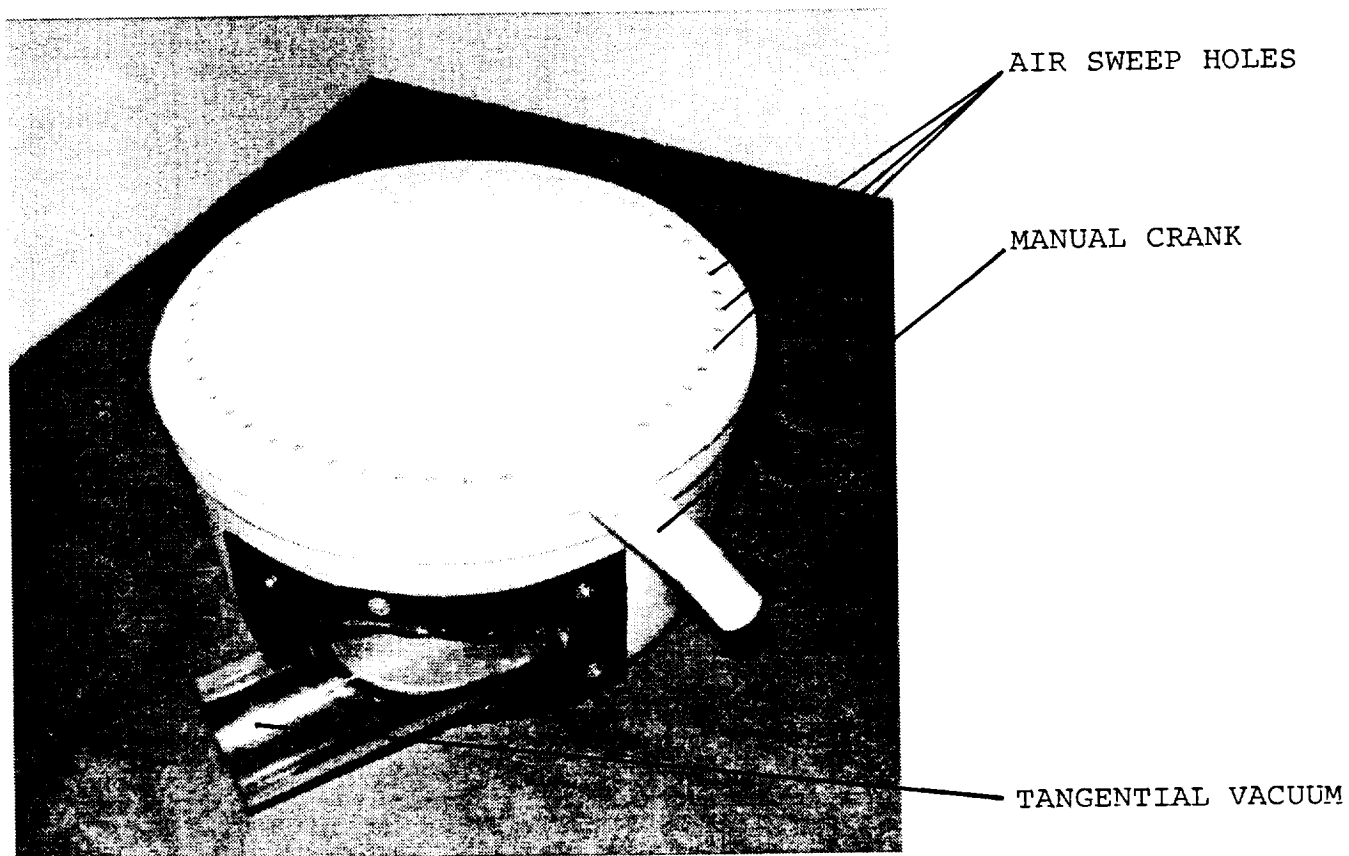
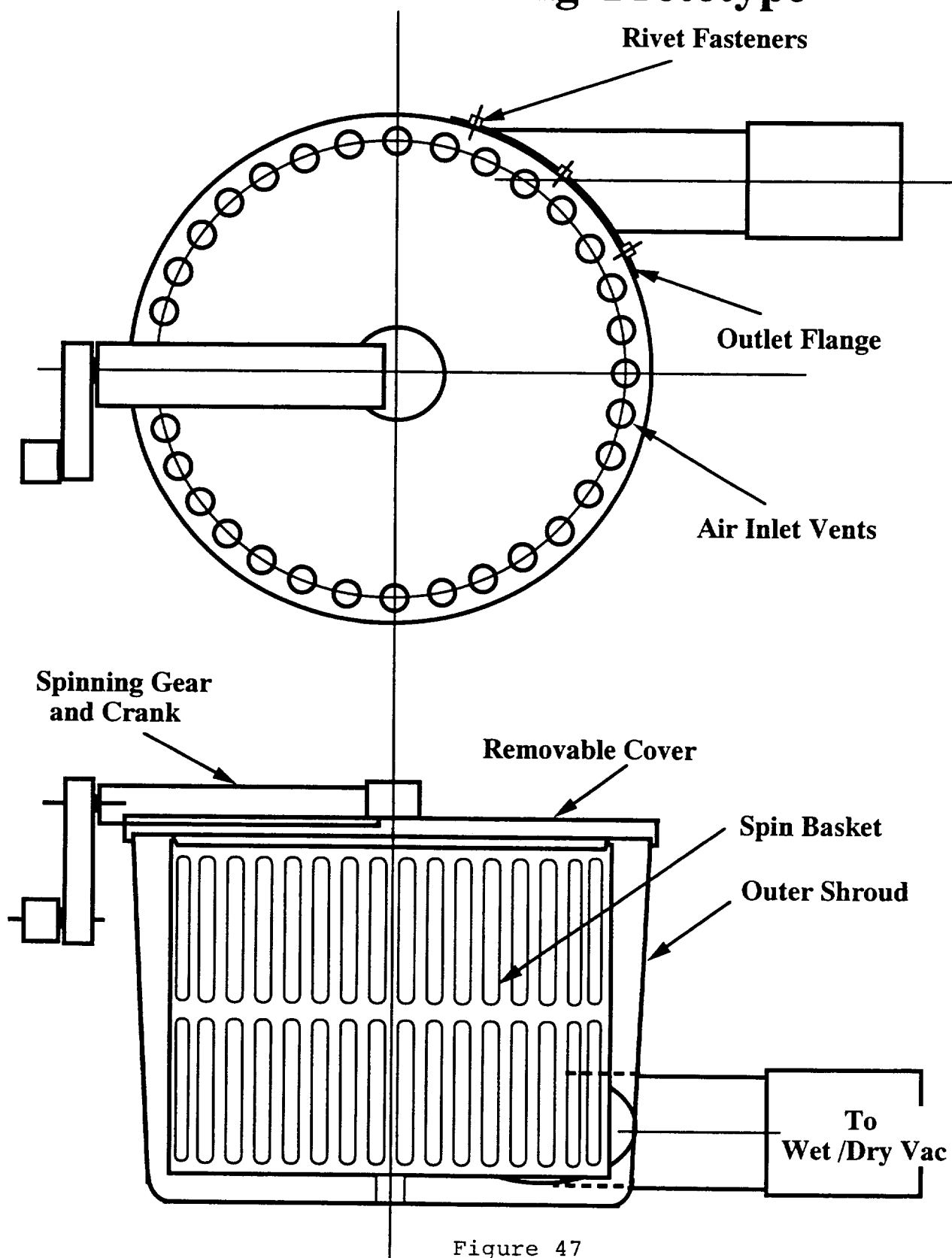


Figure 46

Greens DeWatering Prototype



droplets toward the bottom of the bowl where they could be aspirated away. The spinner was turned in a clockwise direction to enhance the tangential movement of air and water. A second test run using lettuce leaves was very successful in that the air flow was more balanced, with the result that the mechanism, even though it was lightweight plastic, performed well, and the lettuce leaves were dried sufficiently for immediate use in a salad or for storage. The vacuum and resulting air flow was sufficiently strong to immediately collect water spun from the leaves. It is presumed that under zero-gravity, the vacuum would not have to be as strong to eliminate flying water droplets.

A second series of experiments was performed to evaluate the use of this unit on larger, heavier materials. In this test, the objective was to wash and dewater 8 medium-sized potatoes. In this case, the bowl was filled half-full of water, the potatoes were added and the lid put in place. The spinning was started with no vacuum assistance so that the potatoes were thoroughly washed. After a sufficient time interval the vacuum was started and the water aspirated away. After a few seconds of spinning, while nearly dry, the crank effort increased sufficiently that spinning was halted. The spin gearing and drive mechanism was made of light plastic, and there was danger of mechanical failure. The excessive resistance was determined to be a combination of the vacuum, deformation of the spin basket under the load of potatoes that were no longer "floating" in water, and an unbalanced distortion of the basket at the vacuum port that caused contact with the stationary outer shell. The test was deemed a partial success in that under zero-gravity, the initial weight of the potatoes would be nonexistent, the volume of water used in the test would not be present, the construction of the basket and its support would be heavier, and the vacuum force would be less.

It is anticipated that the finished design would have spray nozzles that would provide wash water and make-up air in metered amounts thus reducing the volume of water to be managed and facilitating its aspiration. The prototype design did not have spray capability in the lid of the container because the required space was occupied by the manual spin mechanism. In a finished design, it is anticipated that the drive mechanism would be provided through the base of the unit, allowing top mounting of spray nozzle(s) for air and water. The number of holes required to balance the vacuum and sweep away water droplets will need to be determined experimentally under zero-gravity conditions.

SLICER (BREAD)

Few food products enjoy the universal appeal of freshly baked bread. Accordingly, considerable effort has been applied to developing a bread-baking system for astronaut crews. Concurrent with the production of fresh bread is the need to slice it into usable portions for sandwiches and even breakfast toast. Slicing fresh bread has been found to produce a great deal of debris in the form of crumbs. It was decided that a means of producing uniform slices which would incorporate a means of

capturing loose crumbs as they are made, would be highly desirable. Since probably no more than one or two loaves would be sliced at a time, and probably no more than four in a day, it was felt that a small, compact, light-weight manual device would be more appropriate than an elaborate mechanized or automated unit.

Figure 48 shows a device which positions and restrains the loaf during the slicing operation, serves as a slicing guide, and effectively scavenges loose crumbs produced during the slicing operation. The first concept used dowels to position the slicing knife for uniform slices. This was found impractical from a manufacturing standpoint. The holes used to hold the dowels were too close together and weakened the mounting plate (some broke out between holes). This design was abandoned, and a simplified design was fabricated using saw cuts through a solid plate, spaced at a desired interval for slice thickness. The balance of the design remained the same. The "front" plate was hinged to provide a means of clamping the loaf in place during slicing. The base of the device was cut into a grid form to allow air flow into the plenum sub-base which could be connected to a vacuum source. The grid was cut from two directions at 90 degrees to one another such that the grid retained its structural integrity and yet provided a free passage of air for aspiration. The vacuum line was attached to the underside of the base to facilitate crumb collection.

Several loaves of bread were made using a bread-baking machine and sliced using the prototype guide. Initial trials were performed without aspiration to observe the quantity and behavior crumbs. They were noted to concentrate mainly within the device, with some (about 5%) being carried through the back guide plate to collect behind the device. A final run was made using a 1 1/2 HP vacuum attached to the plenum. The results were very satisfactory. No crumbs were observed inside or outside the device. All loose particulate material was collected by the vacuum system. A very thin blade knife was used in all tests, one with small serrations as contrasted with saw teeth. This resulted in minimum crumb production for all tests and minimum damage to the base plate supporting the loaf. The grid design provided good air flow paths and the plenum ensured that all areas under the loaf had effective aspiration exposure. The slotted design in the knife guide was found to be far superior from a manufacturing standpoint. The 1.25 cm slot spacing appeared to be about right for sliced bread, and the hinged guide plate provided effective positioning of the loaf during slicing. The device was sized to meet the requirements of a loaf prepared in a commercially available bread-making machine. Overall performance of the device was deemed to be very successful. Bread slices were even (after some practice), particle control with aspiration was excellent, and the device was simple to use.

The prototype illustrated in Figure 49 was made of wood for ease of fabrication. If such a device is found to be desirable for use in CELSS, FASI would suggest fabrication from Delrin or some similar material which could provide both ease of cleaning and durability. Considering the volume and fre-

Bread Slicer

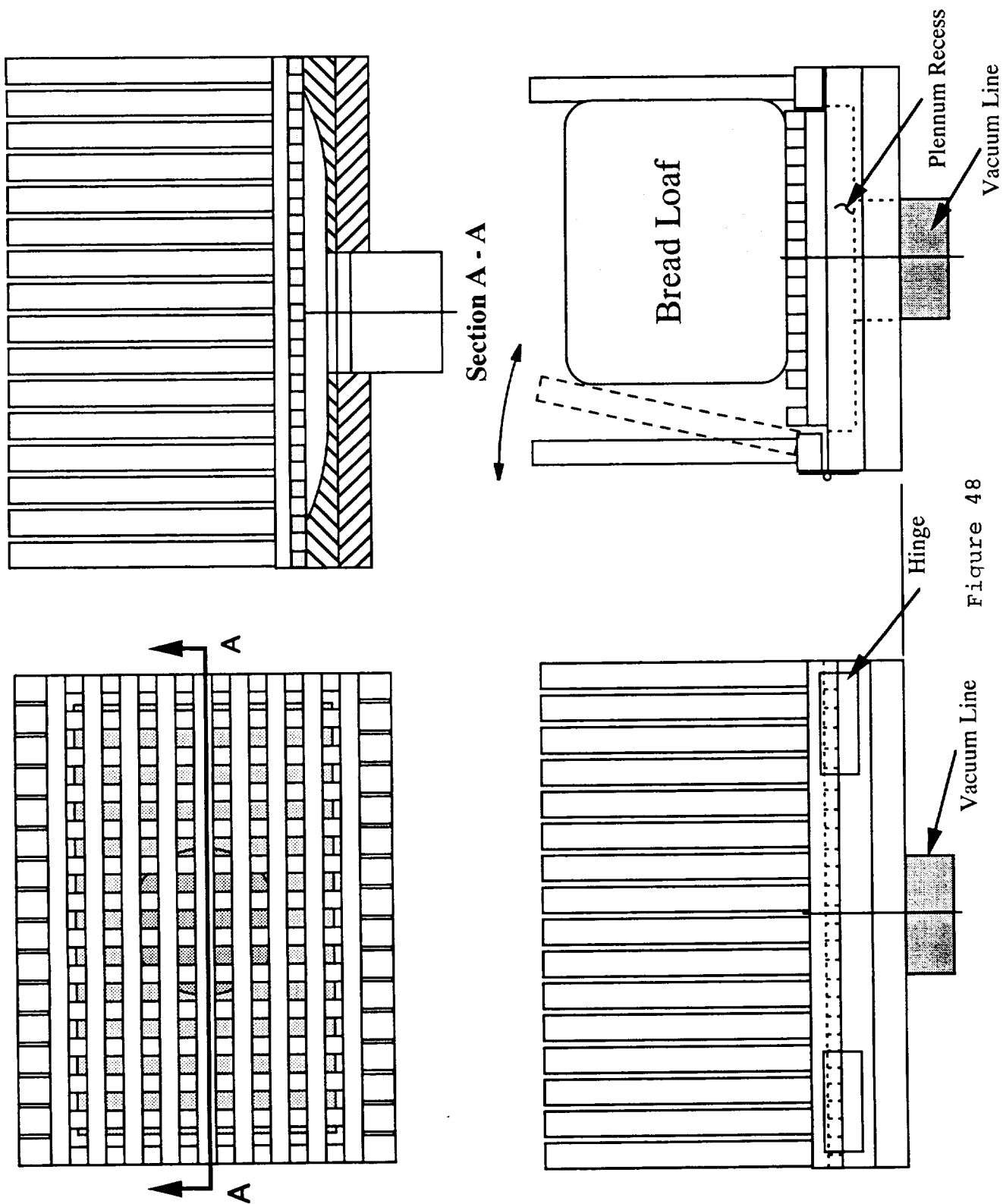
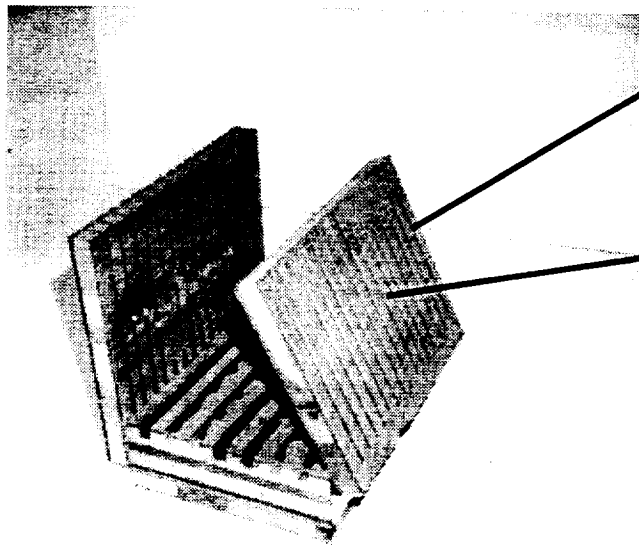
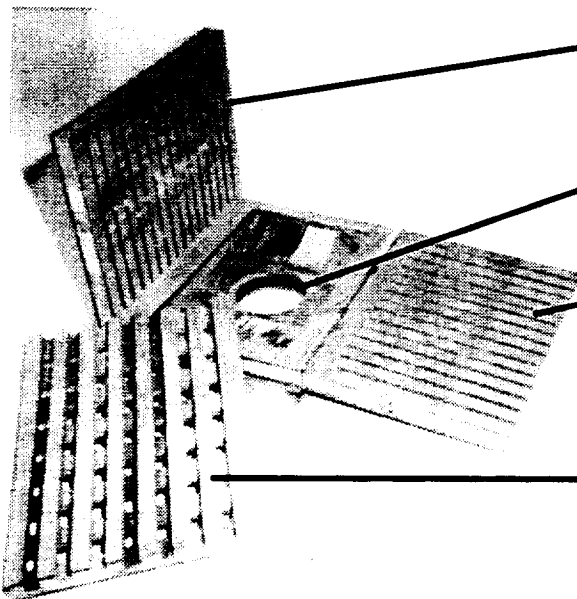


Figure 48



HINGED SIDE TO POSITION AND RESTRAIN MATERIAL TO BE SLICED

SLOTS TO GUIDE SLICING OPERATION

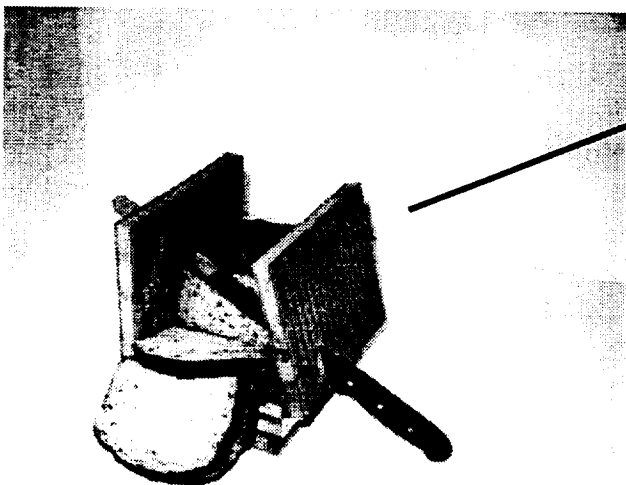


FIXED SIDE

PLENUM AND CONNECTION TO ASPIRATOR

HINGED SIDE

GRID TO SUPPORT MATERIAL BEING SLICED AND ALLOW CRUMBS TO BE ASPIRATED



SLICER JIG HOLDING A LOAF OF BREAD BEING SLICED

PROTOTYPE BREAD SLICER

Figure 49

quency of slicing, the manual device would appear the best approach.

MIXER (MANUAL/BIOMASS) - See Biomass
MIXER (LIQUID & DRY) - See Breadmaking
KNEADER (DOUGH) - See Breadmaking

MEASURING SYSTEM (DRY INGREDIENTS.)

A need was identified for the measuring and transfer of dry ingredients during processing operations and in the preparation of meals in weightless environments. Preliminary tests with a screen basket fitted into the end of a vacuum tube performed very well with wheat and soybeans (Figure 50). When a cloth insert was added to permit the handling of finer materials such as flour, the cloth blinded very rapidly and the full volume was not attainable. Based on these results, a prototype device was constructed of clear plastic which included removable measuring heads representing commonly used volumes (60, 180, and 475 cc), Figure 51.

Coupled to a 1.5 HP vacuum source, the units were evaluated with both wheatberries and soybeans. In an actual 0-G situation, the bulkhead bins would be connected to a slight but constant vacuum source so that the contents remain at the bottom of the bin and are provided with good ventilation. In these tests, the measuring heads were immersed in canisters of wheatberries or soybeans, similar to a bulkhead bin. Because of the higher vacuum, the beans/berries were preferentially pulled into the screen container of the measuring device, with the excess material scraped off to provide an accurate volume. The 60 and 180 cc heads both functioned well in enabling a desired volume of wheatberries or soybeans to be removed from a bulk container and transferred to wherever it is needed. The 475 cc head did not perform as well, being unable to retain a full measure when the device was pulled from the bulk container. Observation indicated that the air flow through the larger diameter head when filled, was insufficient to retain particles against normal gravitational force.

Since diameter was the major determinant of volume in the measuring heads tested above, a second series of heads were constructed and tested in which tube diameter was fixed at that for the 60 cc measure above, and length was the determining factor (Figure 52). With the length adjusted to provide 475 cc, the tube was inserted into the bulk canisters. In the case of both wheatberries and soybeans, the tube immediately filled, and retained a full state as it was withdrawn.

An additional follow-on experiment was conducted to test this new configuration using flour. A fabric liner was placed over the screen to prevent passage by the flour. When the tube was pushed into the flour bin, the tube immediately filled completely. On being pulled from the flour bin, the tube remained full. The excess flour was scraped to a level measure, with the excess fall-

Dry Measure Experiments

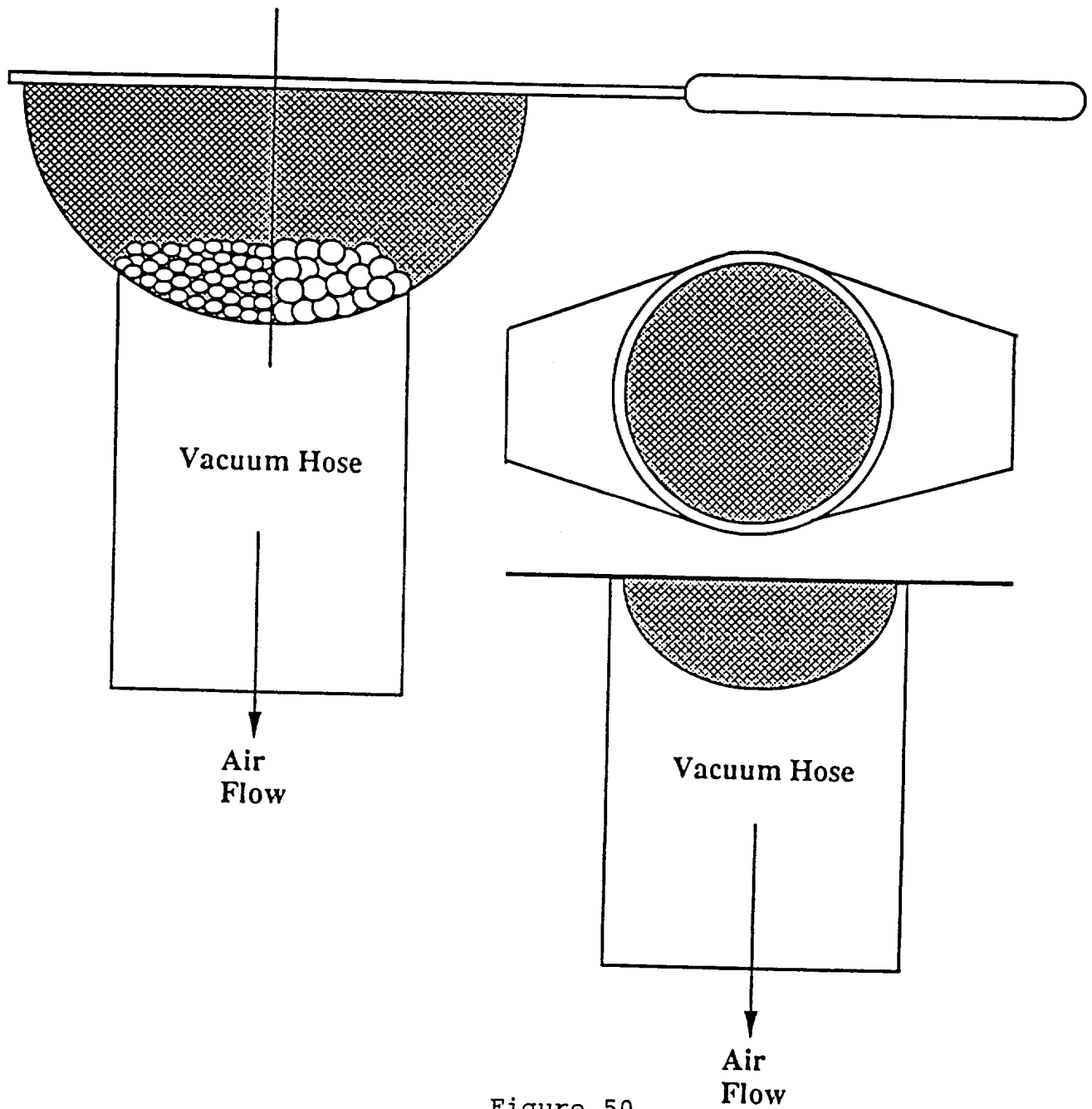
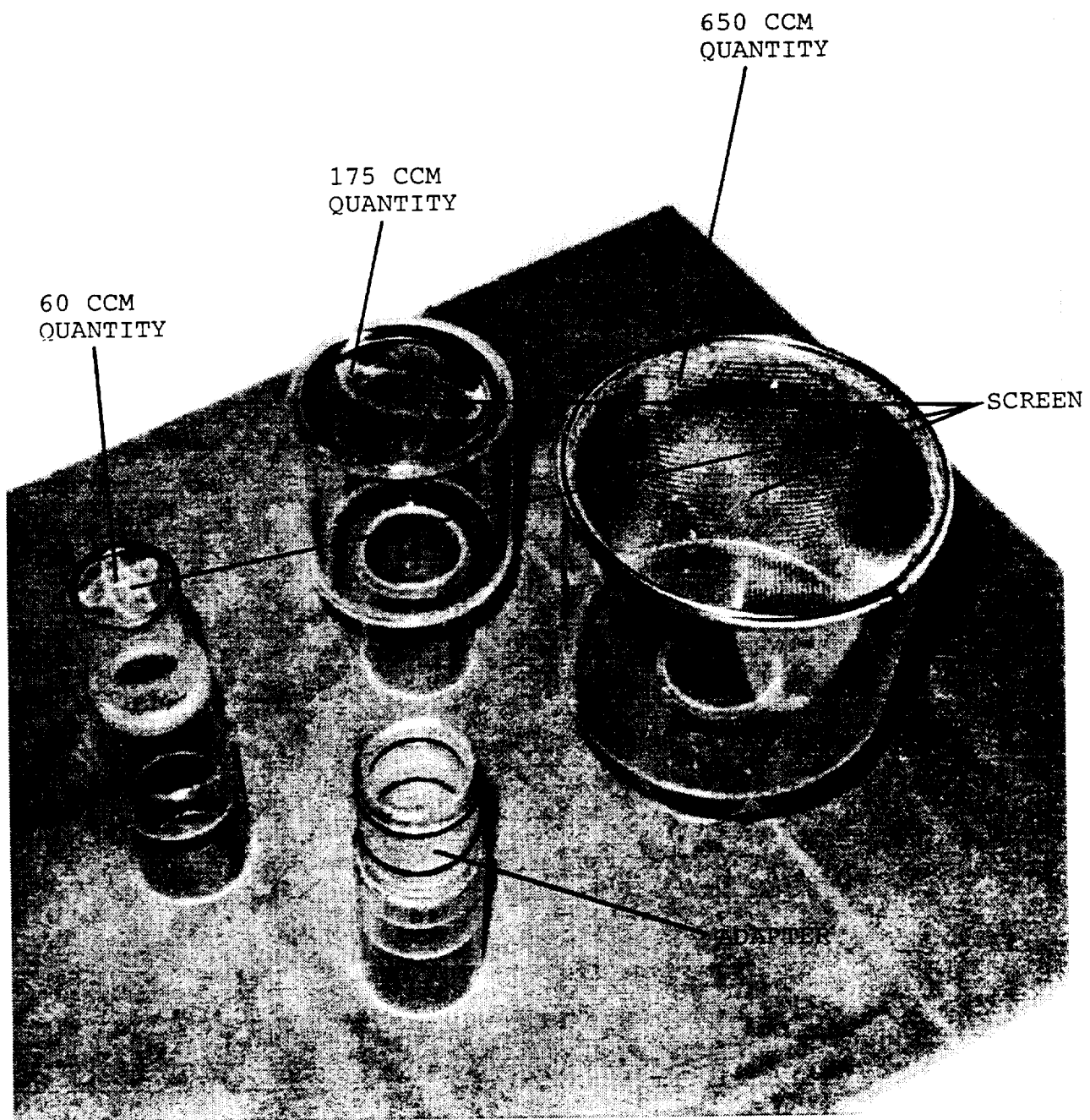


Figure 50



PROTOTYPE SYSTEM FOR DRY SOLID MEASURING,
HANDLING, AND DISPENSING

Figure 51

Fine Particle Handling

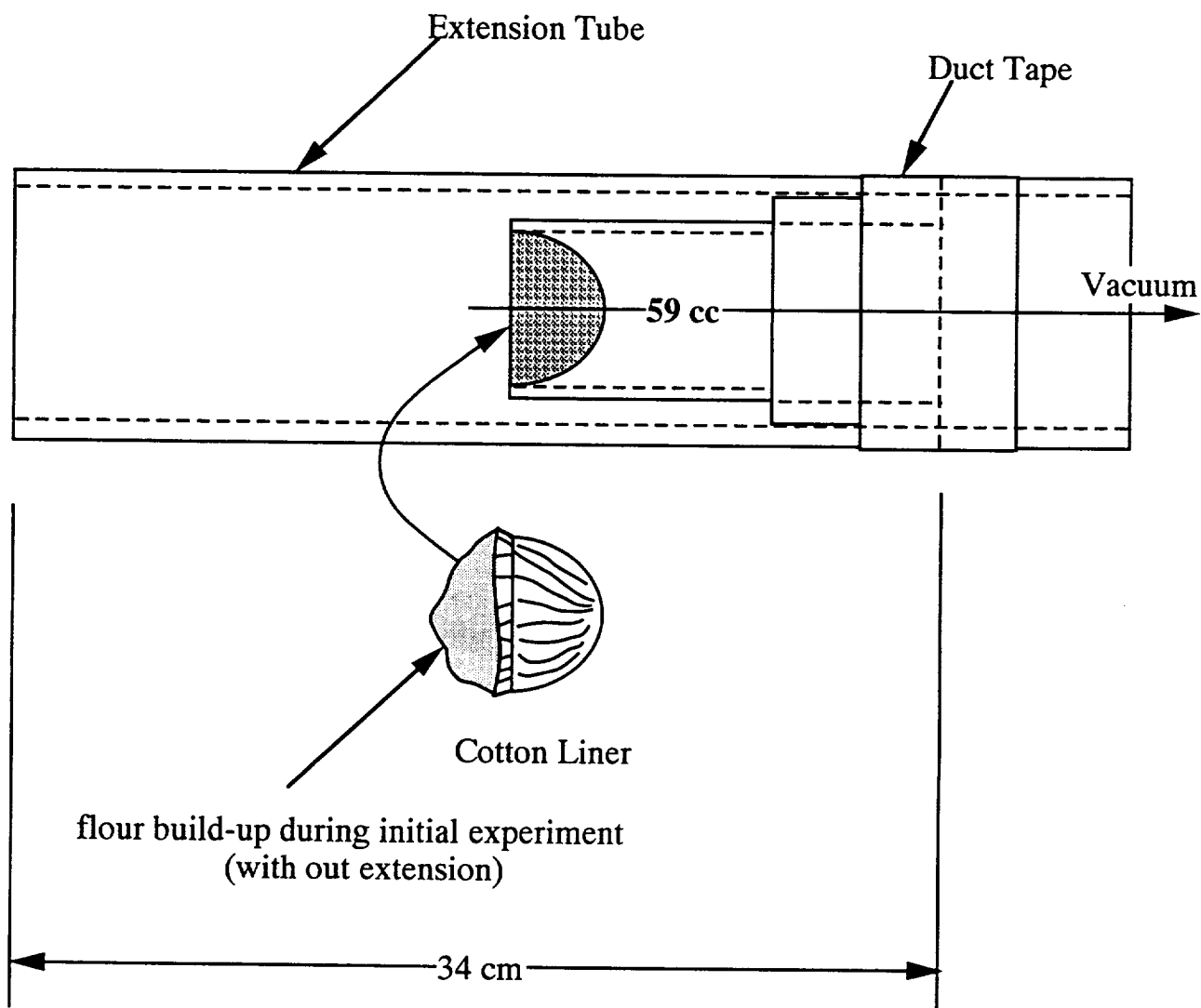


Figure 52

ing back into the bin. The results of these experiments indicate the feasibility of this latter design as a means of measuring and transferring dry ingredients in zero-gravity conditions.

TRAY & PAN (MANUAL) - See ASPIRATION TRAY TABLE

TRAY & PAN (BIOMASS) - See BIOMASS

HOT BEVERAGE "BREWER"/DISPENSER

While nutritionally insignificant, coffee and tea have become a virtual social necessity, and it is assumed that CELSS crews will be no different. While at one time the attraction might have been the stimulants they contain, the success of decaffeinated beverages, and the growing market for new and different tasting coffees and teas, would indicate the possibility that a hot beverage prepared from properly roasted grains, beans, or seeds other than coffee beans, and that did not contain caffeine might find acceptance.

Earlier paragraphs described experiments involving the roasting, milling and hot aqueous extraction of wheat berries to produce a hot beverage which had a distinctive, slightly bitter, but not unpleasant flavor. Additional product and process research will be needed to determine formulation and roasting parameters.

The remaining equipment requirement is a device capable of brewing/extracting the "grounds" in a CELSS under zero-gravity. The following paragraphs describe a concept design which could be used under weightless conditions to prepare hot beverages from "grounds" or to dispense hot water for soups or other foods. A chronic problem with these types of device has been foams/bubbles which become almost impossible to eliminate at 0 G. Foams/bubbles usually develop as a result of free surface and reduced surface tension. A significant portion of the effort devoted to this concept was aimed at developing a system that could avoid foaming problems. As such, it is hoped this design could be helpful in other applications.

BREWING/EXTRACTION

As shown in Figure 53, this unit will make use of an in-line water heater. The rapid response time of these units make them ideal for this type of application. The "grounds" are to be held in an in-line filter pack which the water must pass through and mingle with the grounds. This will allow water soluble material, including color and flavor fractions to be extracted as the water passes into the holding chamber. The filter pack will be a reusable porous container that is accessible from the exterior of the unit. This would allow replenishment of fresh "grounds" without disassembly of the entire unit. The next requirement is that there be no free liquid surface which would allow the formation of air bubbles or liquid droplets. To accomplish this objective, the unit is designed as a cylinder with a floating piston. Initially, before filling, the piston would be put at its 'bottomed' posi-

CELSS Coffee Pot Concept II

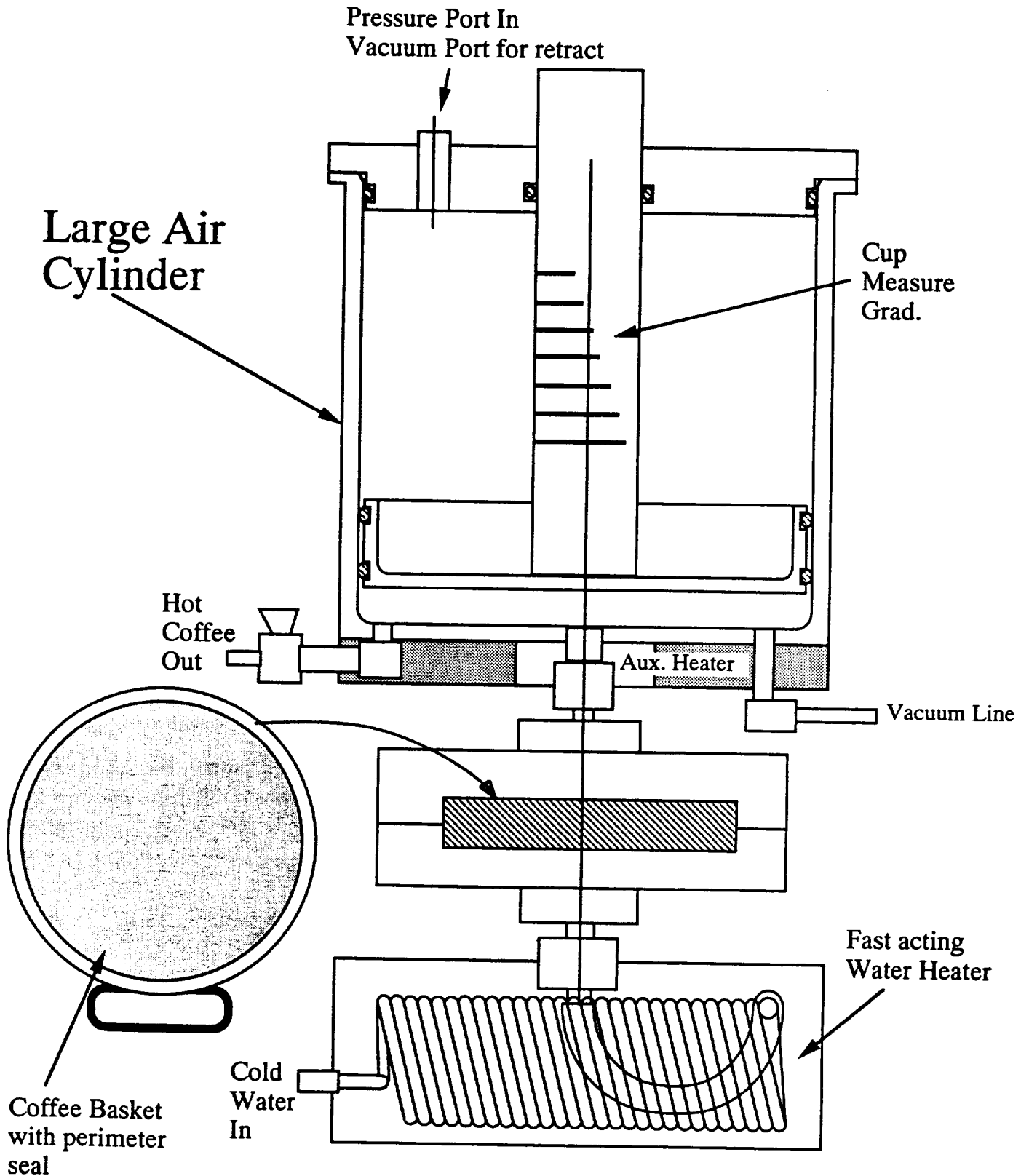


Figure 53

tion to minimize the amount of air present. To further reduce air, a vacuum would be pulled on the unit prior to starting the brewing cycle. When vacuumization is complete, the vacuum valve would be closed and hot water admitted. It would flow through the grounds filter and into the main chamber, pushing the piston ahead of it as needed. Air would be vented from the chamber behind the piston to avoid back pressure. Although not shown in Figure 53, it is anticipated that a heating coil and jacket would be necessary to maintain beverage temperature.

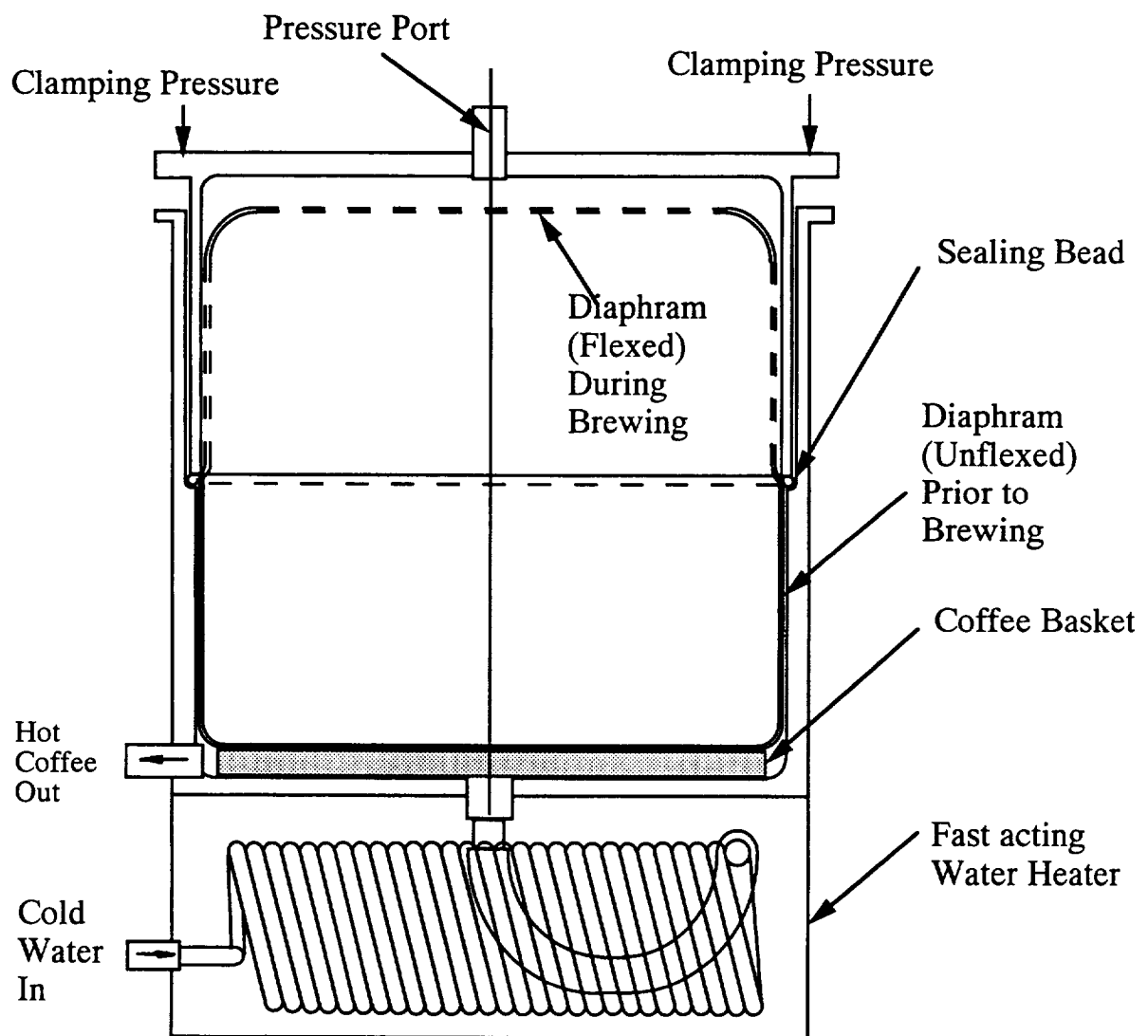
DISPENSING

On completion of the brewing cycle, the water valve would be closed, and a low air pressure would be placed in the top cylinder. As the dispensing valve was opened, the low pressure air would gently force the piston down, pushing the hot beverage out through the dispensing valve.

Several alternative approaches were considered, including the use of a flexible diaphragm in place of the piston, as shown in Figure 54. The general result would be the same, however the interface between the diaphragm and cylinder would be far more complicated and expensive. A spring was considered as an alternative to air pressure for dispensing, but was rejected because of its nonlinearity.

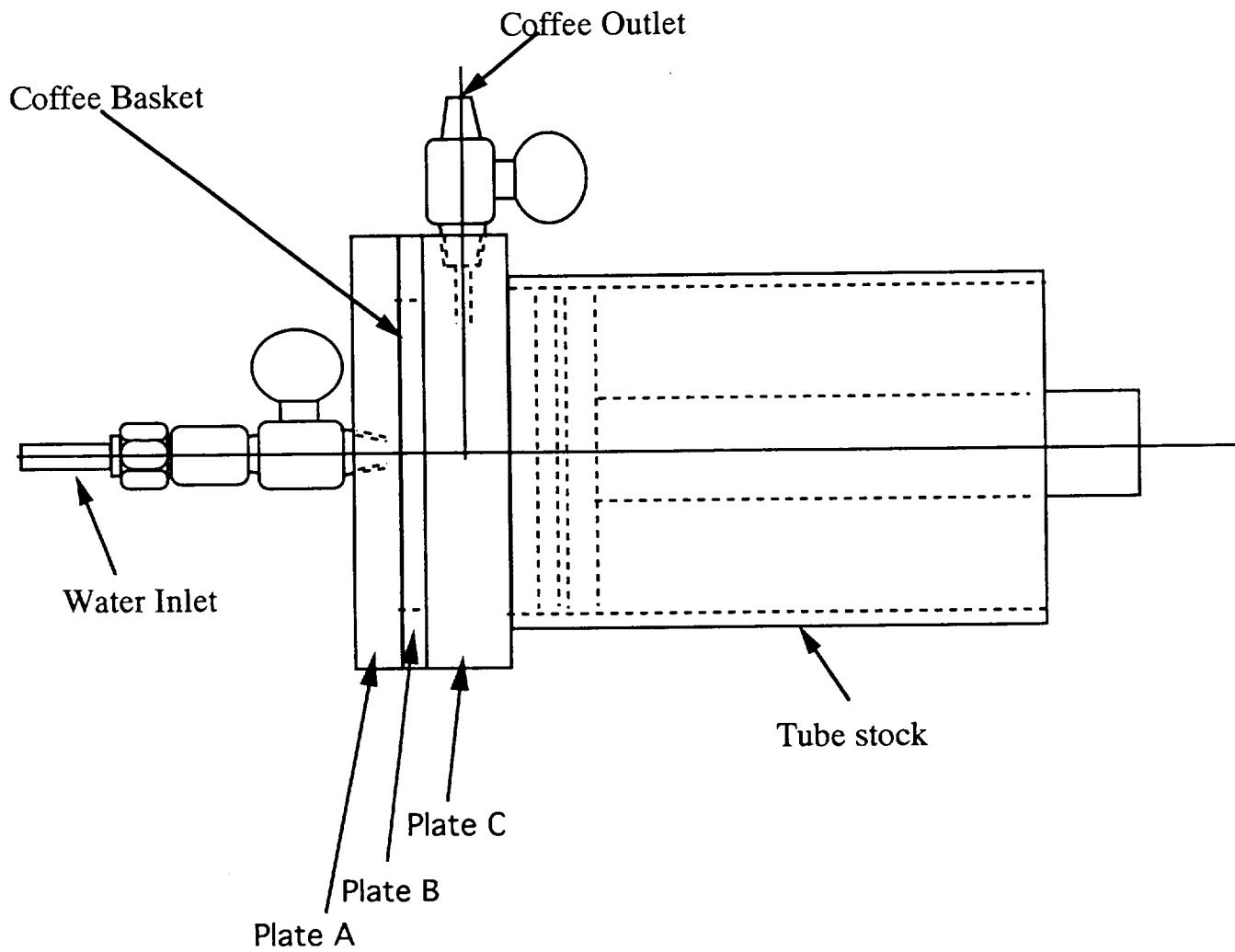
Operation of the brewing device would be very simple, and could be easily automated to allow hot beverages to be available as desired. Little effort would be required of the crew member aside from installing a new grounds filter bag, pushing a start button and waiting for a few minutes for the extraction to be completed. At that point the crew member would connect a drinking container to the discharge spigot and press the discharge/dispensing valve until the container was filled to the desired level. All other operations and valving would be automated, including vacuumization, admitting the hot water, opening the air vent valve, closing the hot water valve, and opening the low pressure air valve.

To test this concept, a prototype of the brewing device was constructed of acrylic plastic, which simplified fabrication and permitted observation of the amount of bubbles trapped within the system. Figure 55 shows the prototype design, and Figure 56 a photograph of the completed prototype after completion of the testing program. As shown in Figure 55, the grounds filter bag was placed in the void space in plate B, and the unit bolted together. Plate C contained an array of small holes positioned to allow passage of fluids between the extraction/grounds chamber and the main cylinder, but to minimize channeling whereby water could by-pass the grounds filter bag. During the prototype tests the amount of air estimated to remain in the 15.24 cm diameter cylinder as a result of the filling operation was approximately 3 cc.



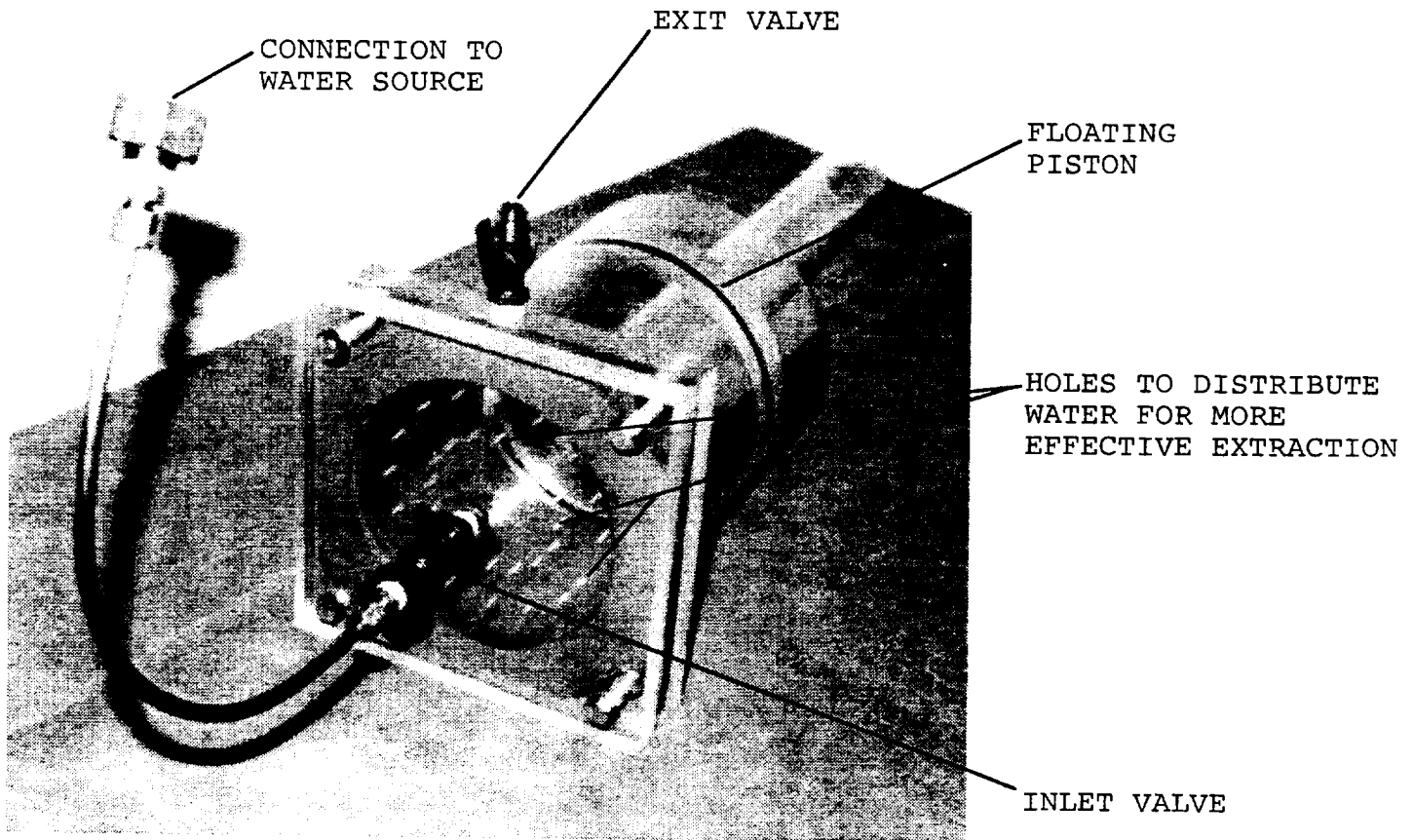
COFFEE POT CONCEPT I

Figure 54



PROTOTYPE BEVERAGE "BREWER" / DISPENSER

Figure 55



PROTOTYPE DISPENSER FOR HOT WATER, COFFEE
OR OTHER HOT OR COLD LIQUIDS

Figure 56

MASS/INERTIA-BASED CLASSIFIER-SEPARATOR

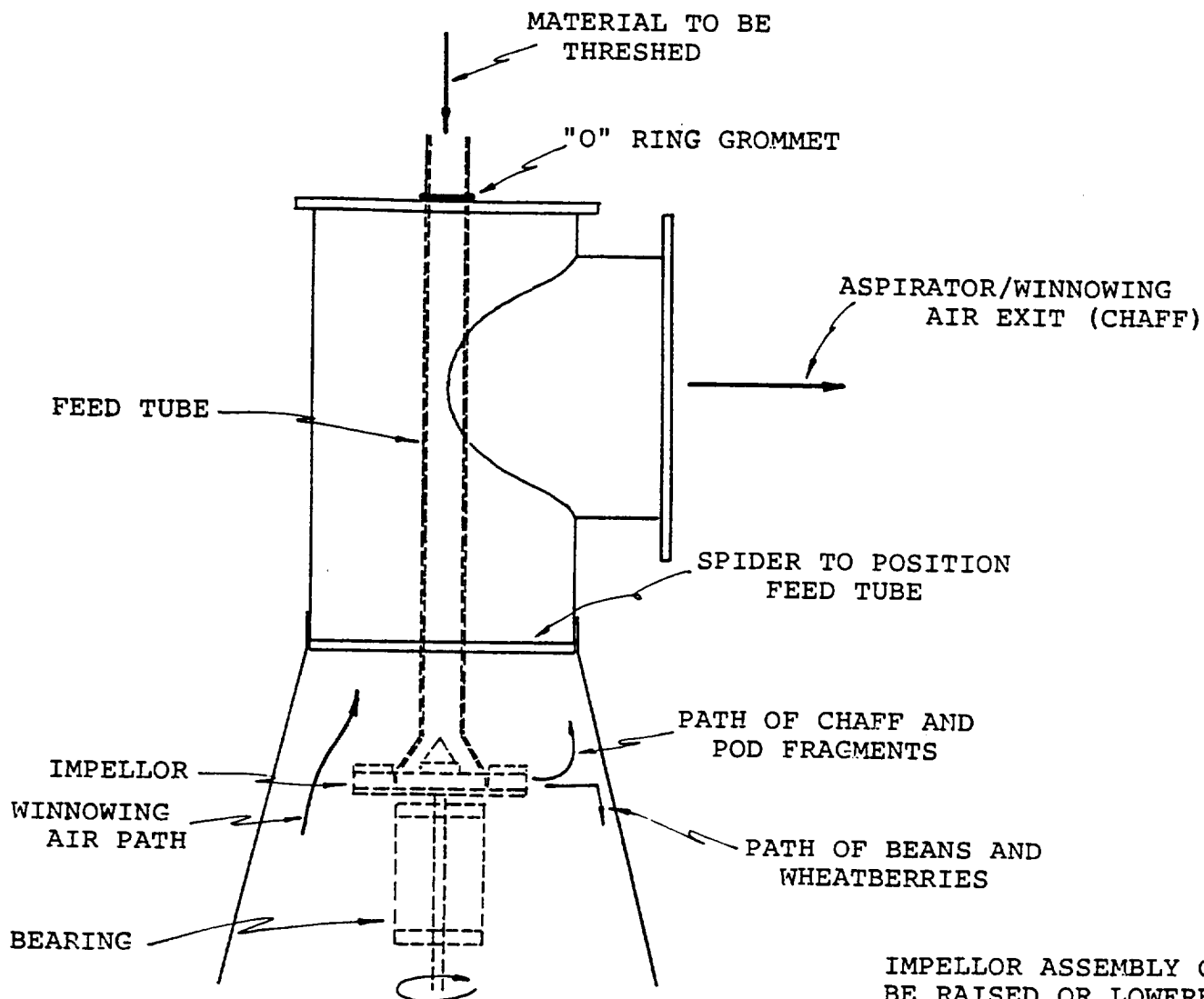
Separation of wheat from chaff at 0 G poses a particular challenge. Commercially this would be accomplished during the threshing operation, using air to separate particles based on settling velocity differences. In the absence of gravity, separators relying on settling velocity/density differences cease to be effective unless other means are used to express these differences. One alternative investigated was a design concept based on a principle similar to that involved in winnowing.

In this concept, particles representing a range of mass, shape, and wind resistance would be fed into an impeller which would impart a radial velocity, accelerating these particles into a "cross-wind" whose velocity can be controlled. It was anticipated that higher mass particles (wheat berries) would be less affected by the "cross-wind" than lower mass particles with higher wind resistance (chaff), and could be "shot" through a window or aperture that would be missed by the lower mass particles caught up in the air flow.

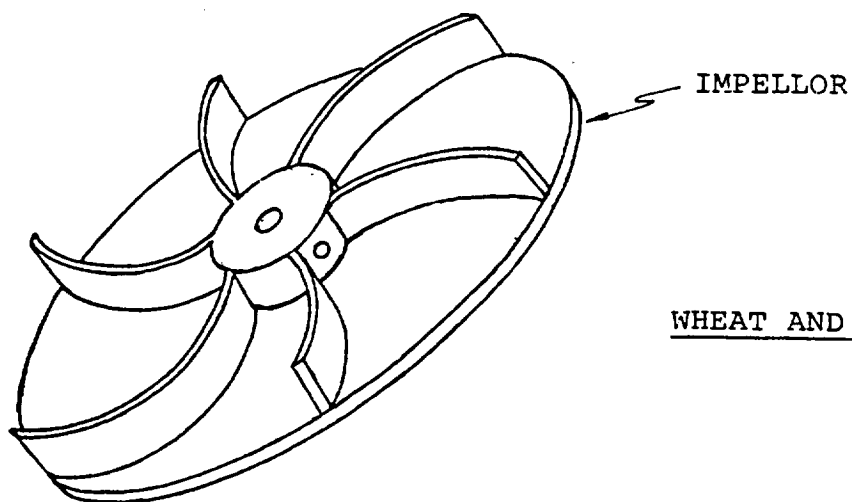
Preliminary tests of this prototype design, shown in Figure 57, revealed that while the unit achieved a consistent 100% separation, the prototype configuration was not able to simulate the behavior of the higher mass particles in zero-gravity. A second prototype, shown in Figure 58, was designed and tested. The results of these trials show that a separation can indeed be achieved using the "winnowing" principle, and that the principle should be effective under weightless conditions. In actuality, because the separation in the prototype required moving chaff in a direction counter to gravity, it is anticipated that separation in zero-gravity should be easier than it was in the prototype at 1 G. In the Figure 58 configuration, and based on the results shown in table 3, effective separation would probably require approximately 2.13 meters per second, whereas at zero-gravity separation might require 1 to 1.5 M/s.

These series of experiments were extended to cover a broader range of spinner RPMs and air velocities as shown in Table 4. The results of these tests indicate that while centrifugal effect induced by the spinner may have an impact at low RPM, it is very minor, compared to air flow, until the RPM gets above 500 to 600. Even at that point, the major factors remain air velocity and particle differences. Figure 59 shows the prototype classifier/separator used for the prototype trials. The most recent configuration uses a 10 cm diameter impeller mounted in a 15.25 cm diam. housing.

Earth-bound prototype tests face a degree of constraint not encountered by space systems, because of the need to overcome gravity. In the case of this specific concept, the air velocity and impeller speed required for these tests is anticipated to be significantly higher than would be needed at 0 G. Figure 60 shows a concept design for a unit based on zero gravity requirements. In this unit a single aspiration source would collect both the wheat berries and chaff, enabling a more compact and energy efficient unit. In this concept, berries

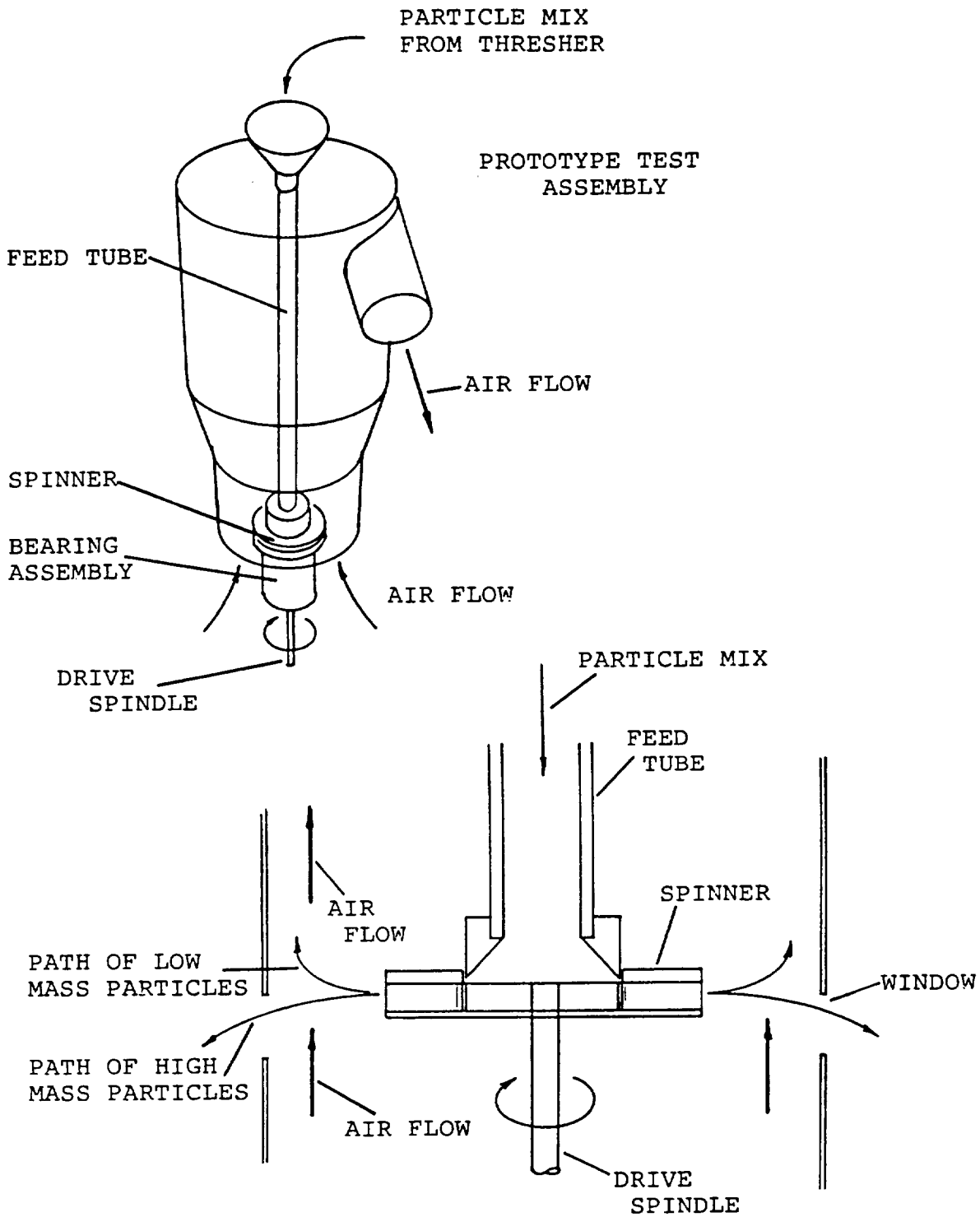


IMPELLOR ASSEMBLY CAN
BE RAISED OR LOWERED TO
INCREASE OR DECREASE
WINNOWING AIR VELOCITY.



WHEAT AND SOY CLEANER/SEPARATOR

Figure 57



PROTOTYPE DEVICE FOR SEPARATING PARTICLES
BASED ON DIFFERENCES IN MASS/INERTIA

Figure 58

INVESTIGATIONS OF THE SEPARATION OF WHEAT AND CHAFF

Run	Total amount chaff	Amount chaff rem'g	% chaff rem'g	Air velocity	Amount wheat	% chaff in wheat	Press. diff.
2	1.15g	0.2g	0.17	1.55M/s	6.0g	3.33	5.8cm
3	1.15	0.10	0.087	1.91	6.0	1.67	8.8
4	1.15	0.025	0.022	1.93	6.0	0.417	8.9
1'	1.07	0.01 est	0.0093	1.95	5.9	0.169	9.1
2'	1.07	0.10	0.093	1.79	5.9	1.69	7.7

Table 3 - MASS/INERTIA-BASED CLASSIFIER/SEPARATOR

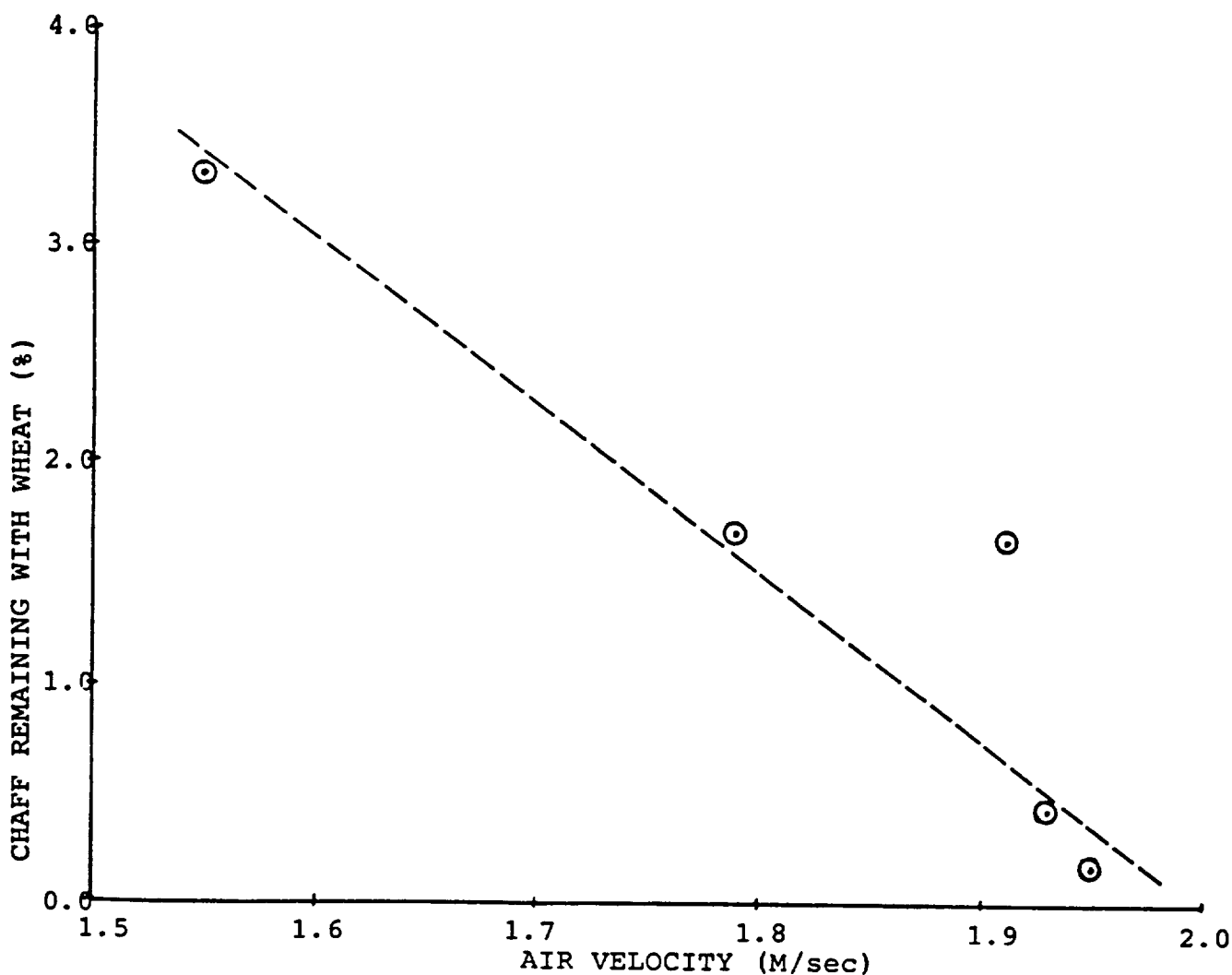


Table 4

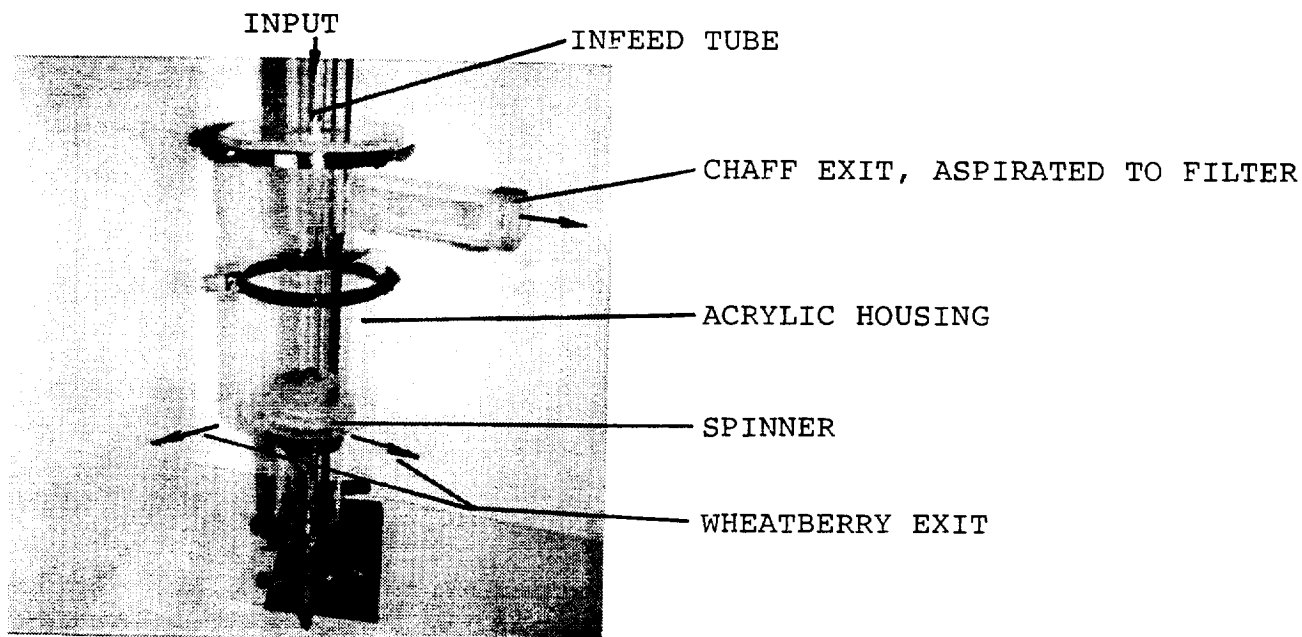
MASS/INERTIA-BASED CLASSIFIER/SEPARATOR---

Effect of Air-Velocity and Spinner RPM on Separation Efficiency

Run	Mat'l	RPM*	Housing Diam. (cm)	Air. Vel. (M/Sec)	Floor Samp. Berr. (gms)	Samp. Chaff (gms)	Filt. Samp. Berr. (gms)	Samp. Chaff (gms)
1	Chaff	205	20.32	1.47	-	0.3	-	0.7
2	Chaff	81.4	20.32	1.47	-	0.2	-	0.8
3	Chaff	48.3	20.32	1.47	-	0.25	-	0.8
4	Chaff	44.8	20.32	1.47	-	0.25	-	0.8
5	Chaff	355	20.32	1.47	-	0.3	-	0.8
6	Chaff	480	20.32	1.47	-	0.25	-	0.8
7	Chaff	250	15.24	3.15	-	0.0	-	1.2
8	Chaff	250	15.24	3.15	-	0.0	-	1.15
9	Chaff& Berries	250	15.24	3.15	5.65	0.0	0.35	1.10
10	Chaff& Berries	400	15.24	3.15	5.85	**	**	1.05
11	Chaff& Berries	400	15.24	3.15	5.60	0.0	0.35	1.05
12	Chaff& Berries	500	15.24	3.15	5.90	**	0.10	1.10

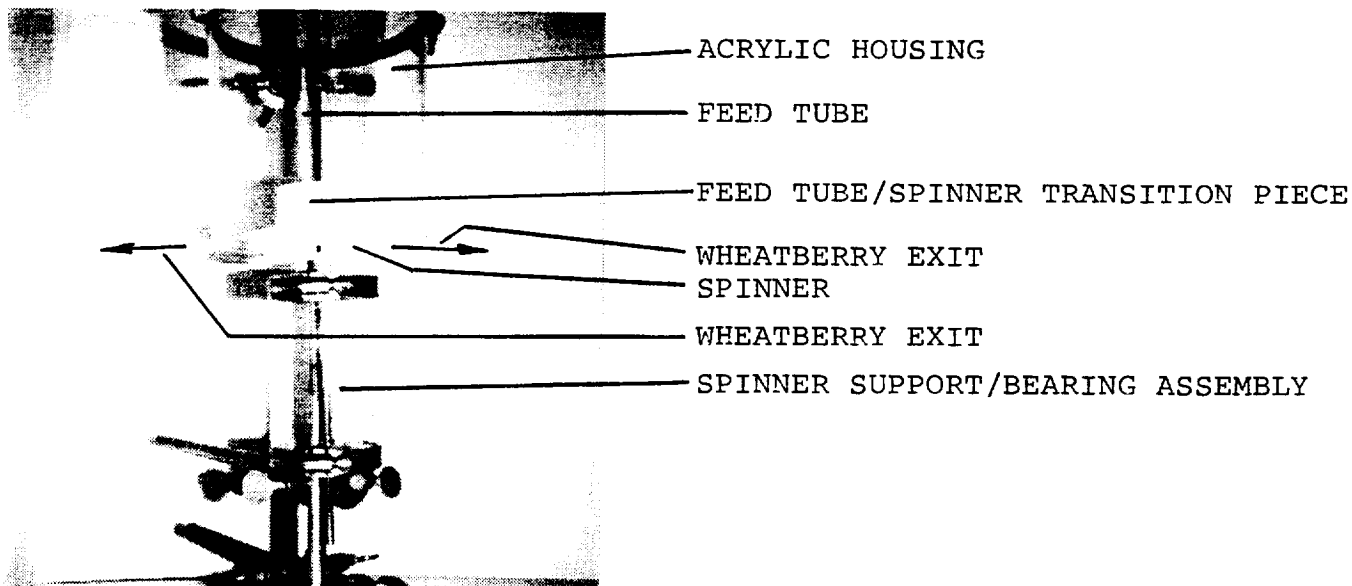
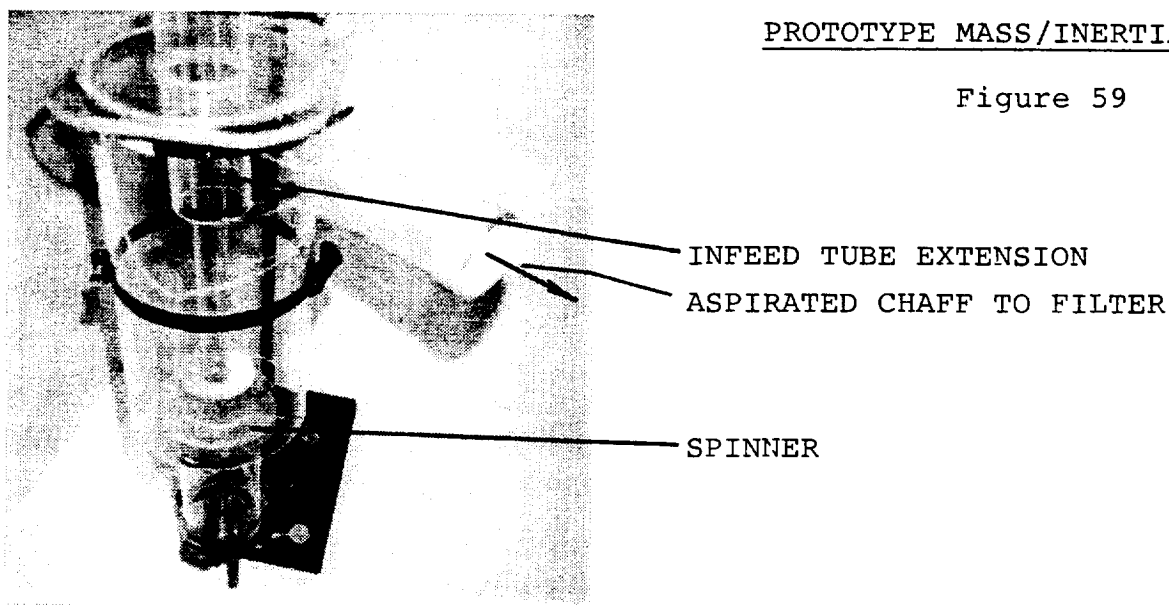
* - Spinner diameter--10.16 cm.

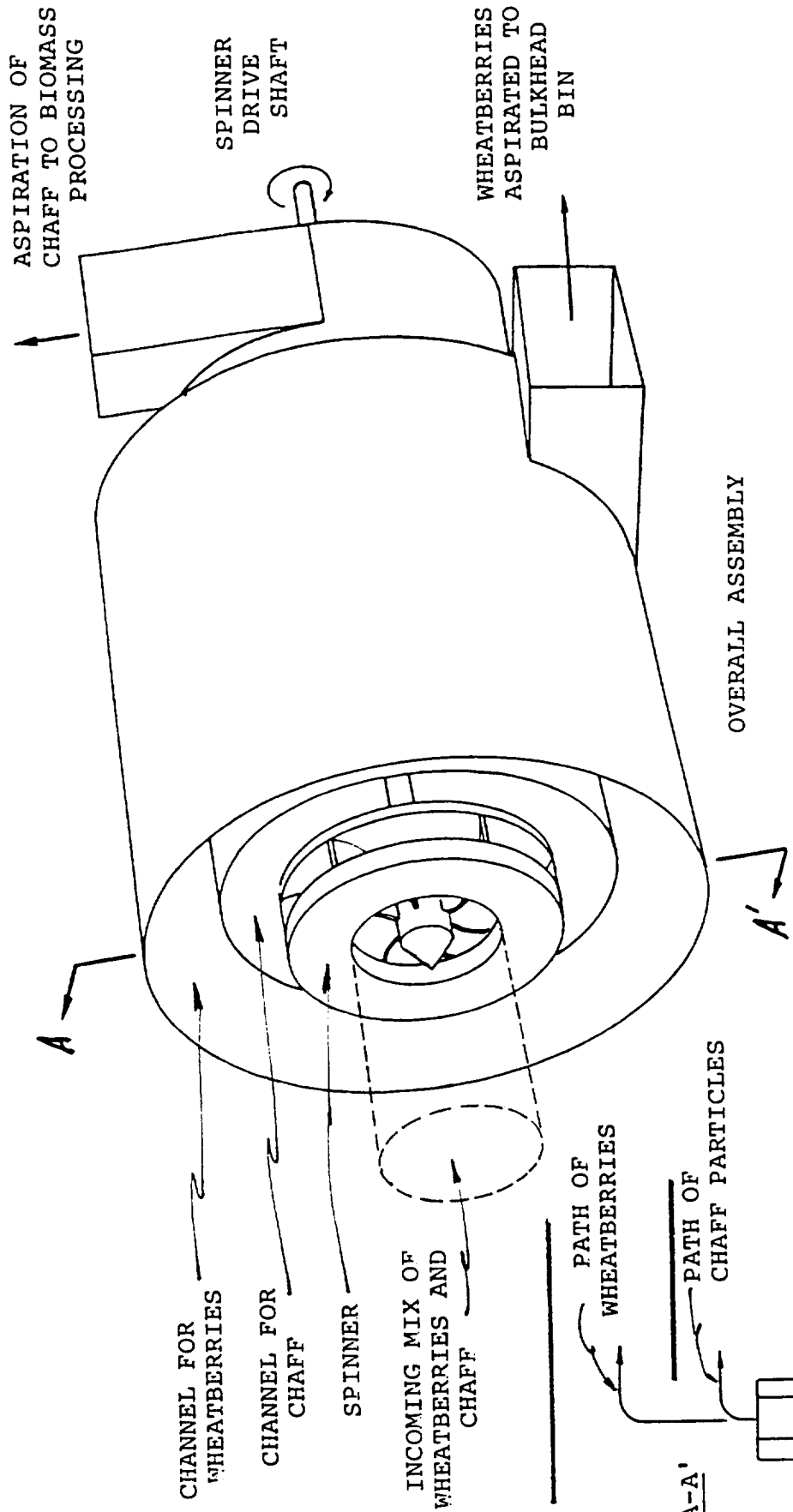
** - Too little to weigh



PROTOTYPE MASS/INERTIA SEPARATOR

Figure 59





SECTION A-A'

INCOMING MIX OF WHEATBERRIES AND CHAFF

SPINNER

SPINNER DRIVE SHAFT

CONCEPT DESIGN OF A DEVICE FOR SEPARATING SMALL PARTICLES BASED ON MASS/INERTIA

Figure 60

and chaff from the thresher would be aspirated to the feed hopper of the cleaner/separator and then mechanically conveyed to the spinner. In addition to its obvious metering function, this conveyor would be designed to break up the chaff into smaller, more easily separated pieces.

The spinner would be surrounded by two concentric housings as shown. The bottom of the first would end about even with the top plate of the spinner and would be about 5.5 to 6.0 cm larger in diameter than the spinner. The second housing would be constructed of a soft polymer to minimize ricochets, extend perhaps 5 cm below the bottom of the spinner, and be approximately 15 cm larger in diameter than the spinner.

BREADMAKER

The two principal problems expected in using a standard breadmaker are first, in the control of dust and the containment of the ingredients in initial mixing, and secondly in the actual kneading of the dough in which the weight of the dough-ball is essential to keep it in contact with the dough kneading blade.

MIXING

The normal procedure for mixing ingredients in the breadmaker are to place all the dry ingredients in the mixing bowl and then add water. The basic ingredients for about a half kilo loaf are:

- 750 ml flour (3 cups)
- 5 ml salt (1 teaspoon)
- 1 packet dry yeast
- 300 ml water (1 1/4 cups)

The immediate problems presented by the absence of gravity are in the control of liquids and small particles, and in the mixing of the ingredients prior to their forming a sticky mass to which all of the particles will agglomerate. Until that point is reached, motion associated with mechanical mixing tends to scatter the ingredients causing dust formation and, in zero-gravity, an uncontrollable mess. A relatively simple solution exists in the form of a slightly modified food processor.

Instead of mixing the ingredients in the breadmaker, they were premixed in a food processor, in this case a Cuisinart. With the Cuisinart running, the flour, salt, and dry yeast were placed in the mixing bowl which, unlike the breadmaker, was equipped with a lid having a centrally positioned hole. The second important difference is that the Cuisinart blade operates at high speed, introducing a centrifugal force, whereas the breadmaker has a paddle too slow to impart useful centrifugal force. As soon as placed in the Cuisinart bowl, the dry ingredients were blended very effectively without any visible formation of dust. The cutting blades rotate near the bottom of the dry mass, the whole of which revolves like a slow whirlpool with enough centrifugal effect that particulates do not reach the center hole.

Water was then added. In 8 to 10 seconds, the entire mass was thoroughly mixed and a sticky ball of dough formed, rotating at about 1 revolution per second above the blades. Practically nothing adhered to the Lexan bowl or to the blades, making clean-up easy.

Based on observations during these tests, the adaptations needed to make a Cuisinart perform bread ingredient mixing in zero gravity would be minimal, and include:

1. TAPERING THE BOWL

Gravity normally permits a dough-ball formed in a food processor to rotate just above the blades, gravity providing the force to keep it in that position. In the absence of gravity, the mixing bowl can be tapered slightly so that if the dough-ball rises above the blades, the wall impact force vectors and centrifugal tendency will drive it down again to the greater diameter at the cutter end. A theoretical taper must exist that would impart a downward force to the bowl bottom equal to gravity. However, there is probably no ideal angle of the taper for different products. An arbitrary angle choice would be 10° . Figure 61 shows a mixer section.

2. AUTOMATING THE SYSTEM

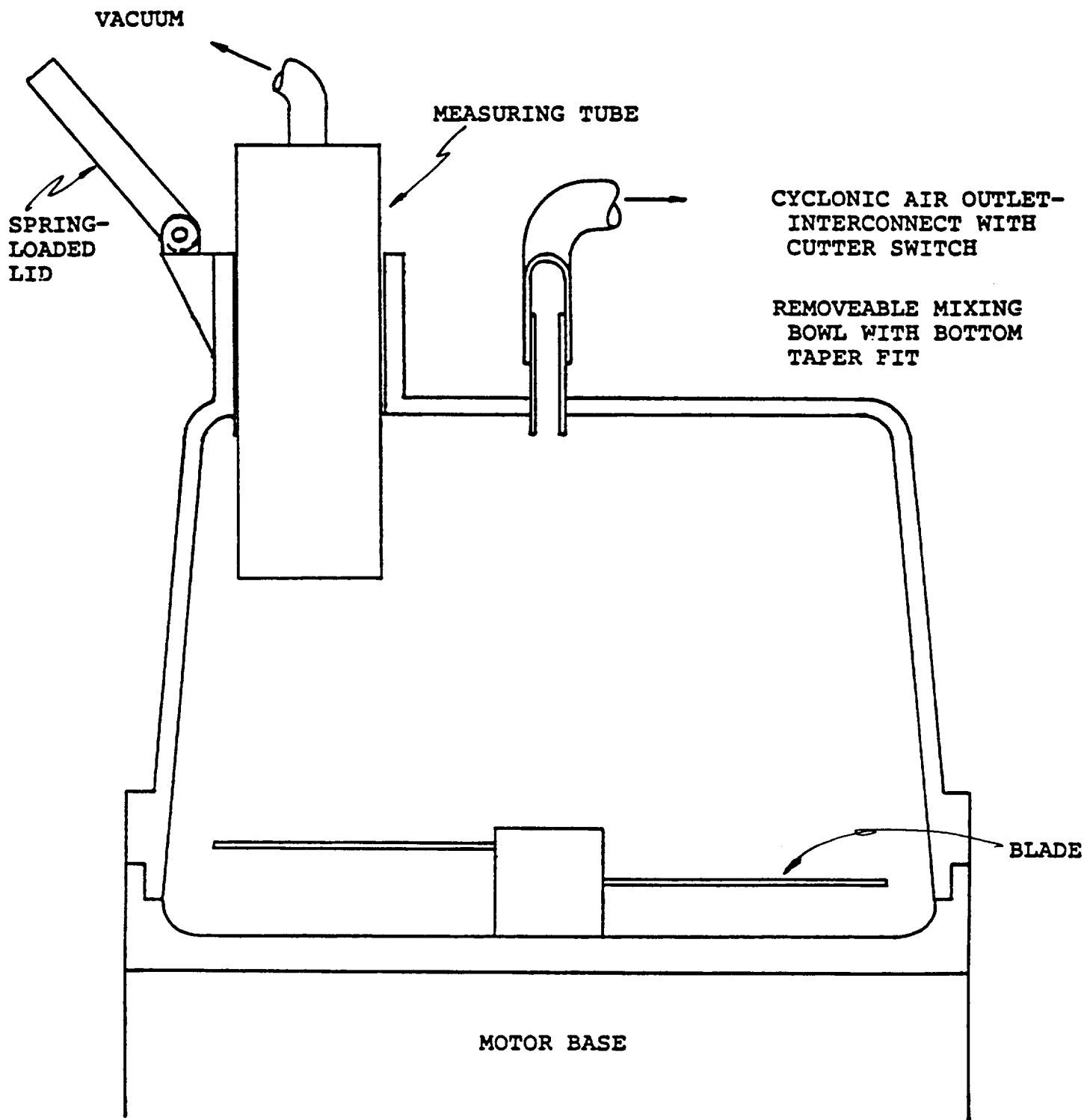
A fully-automated system is likely to be complex, consist of many components, and heavier than a simpler system. On the other hand, a manual (implicitly simple) system could be time consuming and introduce an element of inconsistency. A reasonable compromise may be to accept manual operations which require about a 5-minute block of attention.

The assumptions we have used about making bread are as follows:

- 1.) Bread will be made daily, or at least every other day because of its high acceptability, and the fact that freshness is a major factor in its palatability.
- 2.) The number of people who will eat it will be 8 to 12.
- 3.) Depending on the tastiness of the bread and the attraction of other food, the likely quantity required will be 2 to 3 half-kilogram loaves per day.
- 4.) Preparing the dough and setting up the baking operation should take about 5 to 10 minutes.

Table 5 shows the different steps entailed in the entire operation. To minimize dust, the dough/mixer/cutter should be "on" when the ingredients are added to provide the cyclone effect that prevents escape of dust. The small vacuum outlet at the center of the bowl should therefore be almost entirely free of dust.

Part of the operation is assumed to be automatic and part manual. The column labelled delay represents an estimated normal interval between one step and the next, 5 seconds. The cumulative column shows the time required from initiation of the process to the point where it can be left unattended. In this scenario, the



SOLIDS-LIQUID MIXING DEVICE

Figure 61

TABLE 5. TIME ALLOCATION ESTIMATES FOR BREAD MAKING

STEP	TIME (Min. & sec)			
	<u>Auto</u>	<u>Man.</u>	<u>Delay</u>	<u>Cum.</u>
1. Add yeast				
Insert through feeder tube		00.10	00.05	00.15
Turn on mixer		00.05		00.20
2. Add water				
Prime syringe		00.15	00.05	00.40
Insert syringe		00.10	00.05	00.55
Discharge syringe		00.15	00.05	01.15
3. Aspirate salt				
Hopper				
open		00.05		01.20
insert empty measure		00.10	00.05	01.35
charge measure			00.05	01.40
remove full measure		00.05	00.05	01.50
close		00.05	00.05	02.00
Move measure to mixer		00.05	00.05	02.10
Charge mixer				
open feeder tube		00.05	00.05	02.20
insert measure		00.05	00.05	02.30
dump salt		00.05		02.35
4. Aspirate Wheat				
Hopper				
open		00.05		02.40
insert empty measure		00.10	00.05	02.55
charge measure		00.05		03.00
remove full measure		00.05	00.05	03.10
close		00.05	00.05	03.20
Move measure to mixer		00.05	00.05	03.30
Charge mixer				
open feeder tube		00.05	00.05	03.40
insert measure		00.05	00.05	03.50
Dump flour		00.05		03.55
5. Mix ingredients				
Turn on processor		00.05	00.10	04.10
Stop processor		00.05		04.15
6. Transfer dough				
Remove top		00.10	00.05	04.30
Push dough ball into pot		00.20	00.05	04.55
Extract starter yeast ("chef")		00.45	00.05	05.45
Replace top		00.05	00.05	05.55
Wash				
7. Start bread-maker		00.05		06.00
Knead & bake bread				4 hr
8. Remove baked loaf		01.00		

Notes on Table 5

1. Yeast

In baking tests, standard commercial dried yeast has been used. In space, yeast would be taken from each new batch of dough and cultivated to provide a continuing source. The basic procedure is to start with a "chef", a walnut-sized sample of dough. To this is added more water and flour to make a "levain" which is kneaded and allowed to rise. The procedure is repeated another two or three times to produce a new yeast about the size of a tangerine for the next bake. A method of preparing yeast has not been devised yet, but will be the subject of a future report.

2. Salt

Salt is an essential ingredient of most food. It can be obtained by recycling, but a method to do so has not yet been devised. Salt production will be the subject of a future report.

3. Hopper

The hoppers envisaged are of the type shown in Figures 69 or 70 of this report.

4. Measure

The measures envisaged are of the type shown in Figure 52 of this report.

5. Wash

The blade and bowl were very clean after mixing. The little flour that remains tends to dry out and can be blended with the next batch of bread. It may be that the wash step could be foregone with no compromise of adequate sanitary practices.

time is 6 minutes, after which the operation becomes automatic and need not be attended to until the bread is baked and ready to remove.

KNEADING/BAKING

The commercial Turbo Baker II described in earlier reports does a very satisfactory job of automatically baking bread. Its principal drawbacks for a zero-gravity application are essentially: 1.) the difficulty of initial mixing, and 2.) the question of how to have the dough blade knead the bread without gravity.

The first problem seems to have been overcome by the premixing procedure described above. The second problem appears to be solvable by restraining the motion of the doughball during the kneading operation.

A spring device was fabricated and attached to the breadmaker. Its function was to maintain a small pressure on the dough mass to keep it in contact with the dough blade when the breadmaker was turned on its side. Orienting the whole system in this manner provides a simulation of orbital conditions by eliminating the gravity force that keeps the dough weighted down on the kneading paddle. The adaption is shown in Figures 62 and 63. What the system does is provide a nearly constant 500 gm force on the dough to simulate its normal weight. The actual spring rate is approximately 22 gm/cm, so the range of pressure variation over the observed travel of the disc (roughly 5 cm) is about 25%. The disc rotates with the dough ball and the manner by which the dough is kneaded is therefore not significantly changed.

In the test, the dough was premixed as described above, then transferred with a spatula in one motion into the breadmaker pot. What was observed, and the conclusions drawn are:

The surface of the disc in contact with the dough is not Teflon-coated, so the dough adheres to it to some extent, but only in the form of dry flakes. At no time did the disc cause the ball to divide. In fact the dough stayed in one uniform ball throughout the kneading operation unlike the normal operation where one ball often becomes two. If anything, the disc provides an improvement in this aspect.

Occasionally the dough mass was lifted off the blade and stuck on the pot wall so that the blade no longer contacted the mass, and appeared to turn aimlessly. Applying a little extra pressure to the disc spindle would immediately push the dough mass back in contact with the blade. It turns out that this is unnecessary. The dough is so plastic that the spring pressure will eventually break the dough free from whatever surface it is adhering to and the kneading will return to normal.

At no time during the kneading operation was the disc pressure removed, but it did not appear to inhibit the dough's rising. Because the glass top had to be removed to fit the spring mechanism, the baking sequence of the cycle was cut

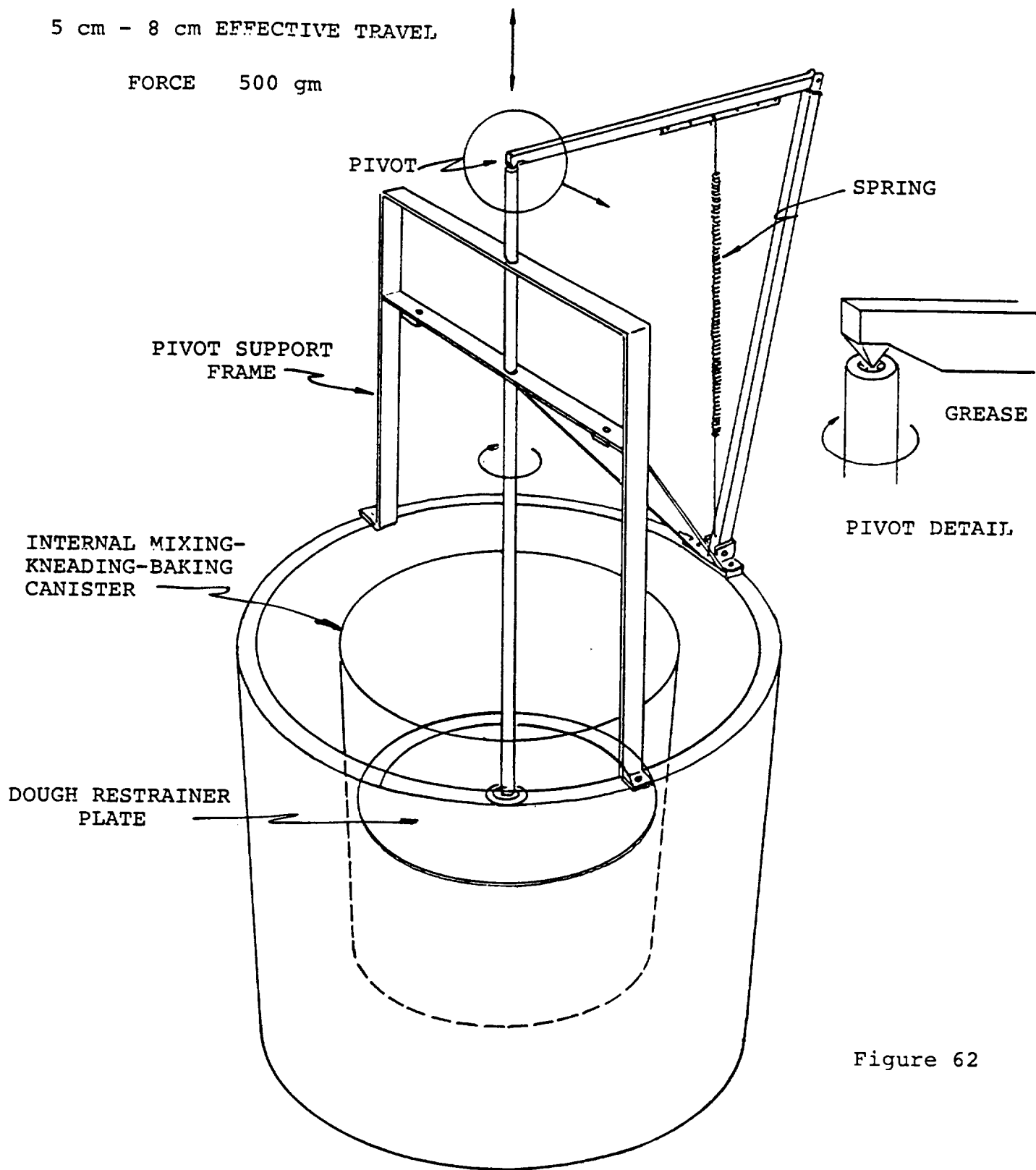
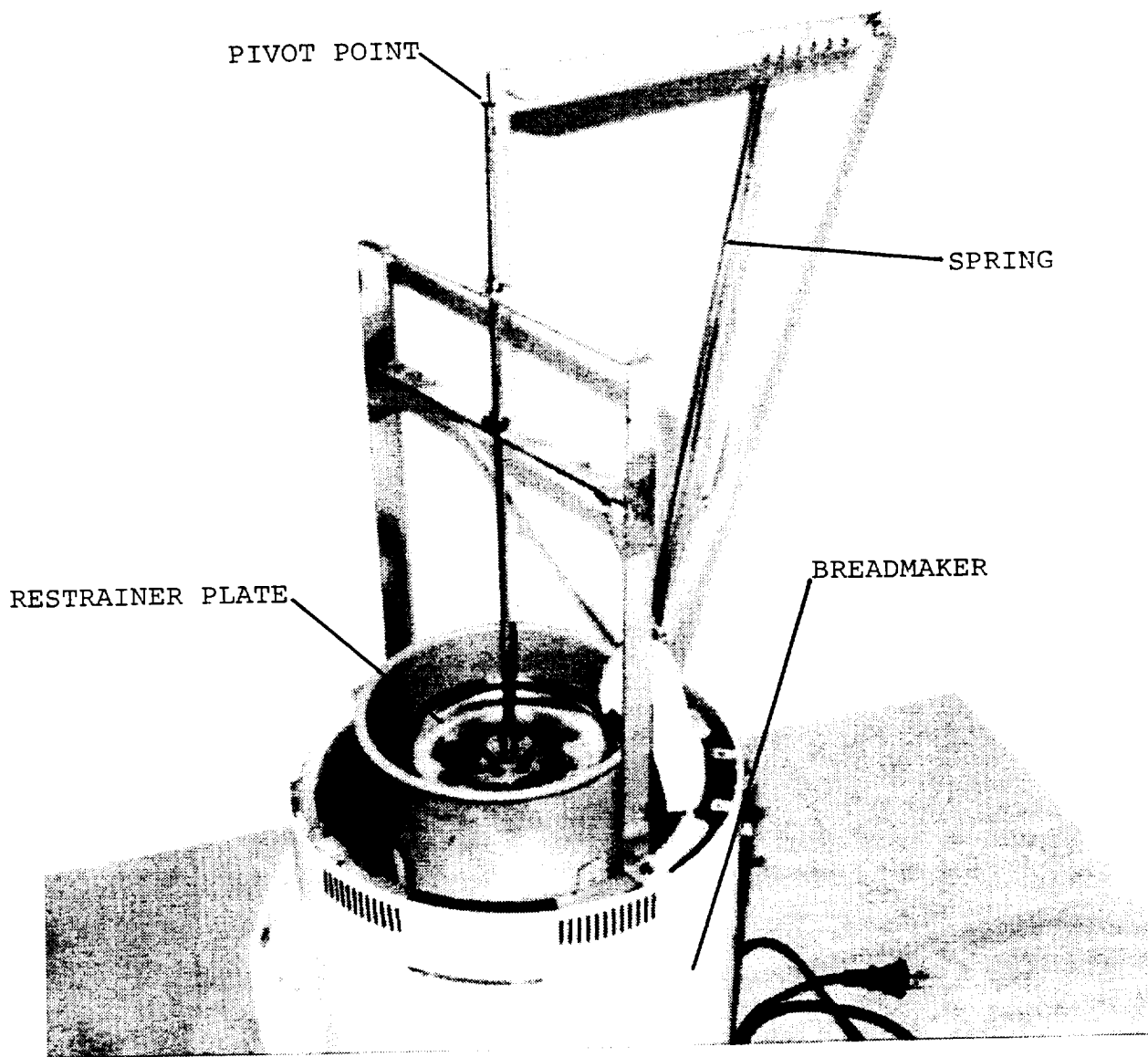


Figure 62

BREADMAKER MODIFIED FOR ZERO-GRAVITY OPERATION



PROTOTYPE SYSTEM FOR KNEADING
DOUGH IN ZERO-GRAVITY

Figure 63

short. One can only speculate on the consequences of retaining the pressure during the bake. If anything, it might make a slightly denser bread, but it would change the nature of the crust. The crust formed against the sides of a baking pan is different from that on the top. Constraining the dough in all planes would therefore eliminate a surface, or "free" crust. Generally the "free" crust is preferred, and European breads such as baguettes try to maximize the proportion of free-formed crust. It would be possible to remove the dough from the pot, shape it as desired, and put it in a radiant oven. In this way, a truly superior bread with all surface "free" crust can theoretically be baked in zero gravity. A conceivable alternative, possible with automation, might provide for the disc pushing the dough into the bottom of the chamber and then retracting during the rising and baking operations.

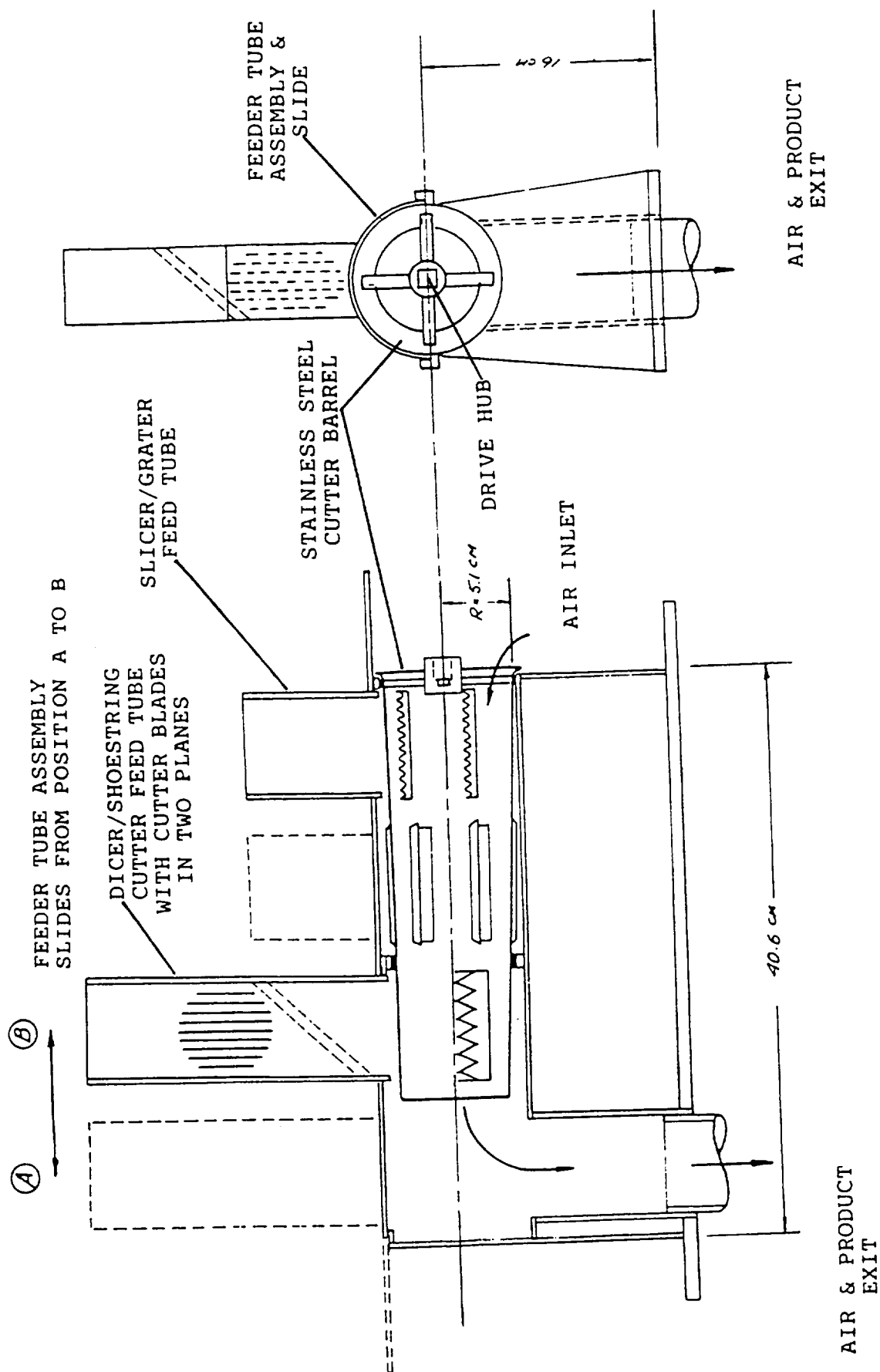
The clearance between the disc and the sides of the pot is about 1.25 cm at the full expansion of the dough. (The pot is slightly tapered for easy removal of a baked loaf.) Because the dough is thixotropic, it tends to ooze out between the lower side of the pot and the disc when the kneading blade is at rest and the dough is rising. It did not flow as far as the pot lip in the first, hour-long rise, and when the second kneading operation begun, the dough immediately reagglomerated under the disc. In the absence of gravity, this would not be a problem because all of the flow was gravity-induced. The spring pressure is insufficient to force the dough between the disc and pot sides.

Glass lids used on heated vessels such as the Turbo Baker should be eliminated in favor of Lexan or similar materials. While it is desirable to be able to observe certain operations in progress, the hot glass could result in incapacitating injuries to crewmembers and jeopardize a mission.

SLICER, GRATER, DICER, SHOESTRING CUTTER

A major objective of the equipment design is to minimize manpower to set it up, wash it, and store it. None of the commercial-type equipment meets these criteria. What is needed is a single unit which contains a selection of the commonly-used shapes which can be accessed without changing parts, and which can be cleaned without dismantling.

It appeared at the outset that the Kitchen Aid/K-Tec-type was more amenable to a single multi-purpose design. The potential lay in joining three of the typical truncated cone cutters to form a single cylinder with three sets of cutters. Figure 64 shows the design that evolved. Three sets of cutters are incorporated into a single rotary cylinder supported in a body that can accommodate various kinds of throats. the cylinder is designed to be rotated by either a built-in or detachable power-pack drive. Shapes that can be produced by the design shown are



SLICER/GRATER/DICER/SHOESTRING CUTTER

Figure 64

MATERIALS: PLASTIC AND STAINLESS STEEL

thin slices, gratings, 6 mm dices, and 6 mm shoestrings. In operation, potatoes or sweet potatoes are pushed down the selected throat to contact the cutter blades. Shoestrings are made by using the end throat without any cylinder cutter. The prototype constructed for evaluation is shown as Figure 65.

The cut forms are deposited into the inside of the cylinder from where they are aspirated into a receiving chamber.

The initial trials were with potatoes trimmed to fit the two throats (approximately 8 cm x 5 cm ellipses). The results were quite acceptable, and the concept of the design was deemed valid. However, there were some problems with the prototype:

The shoestring cutter was unsatisfactory. Too much force had to be applied to thrust a potato through the two sets of stationary knives in the throat. A revised design aimed at reducing the force required is presented in Figure 66. In this configuration, the blades are sloped, but are combined to provide support and prevent blade deformation which was observed in the tests.

The bearing design should be simplified to facilitate removal and reassembly of the cutter cylinder in the body.

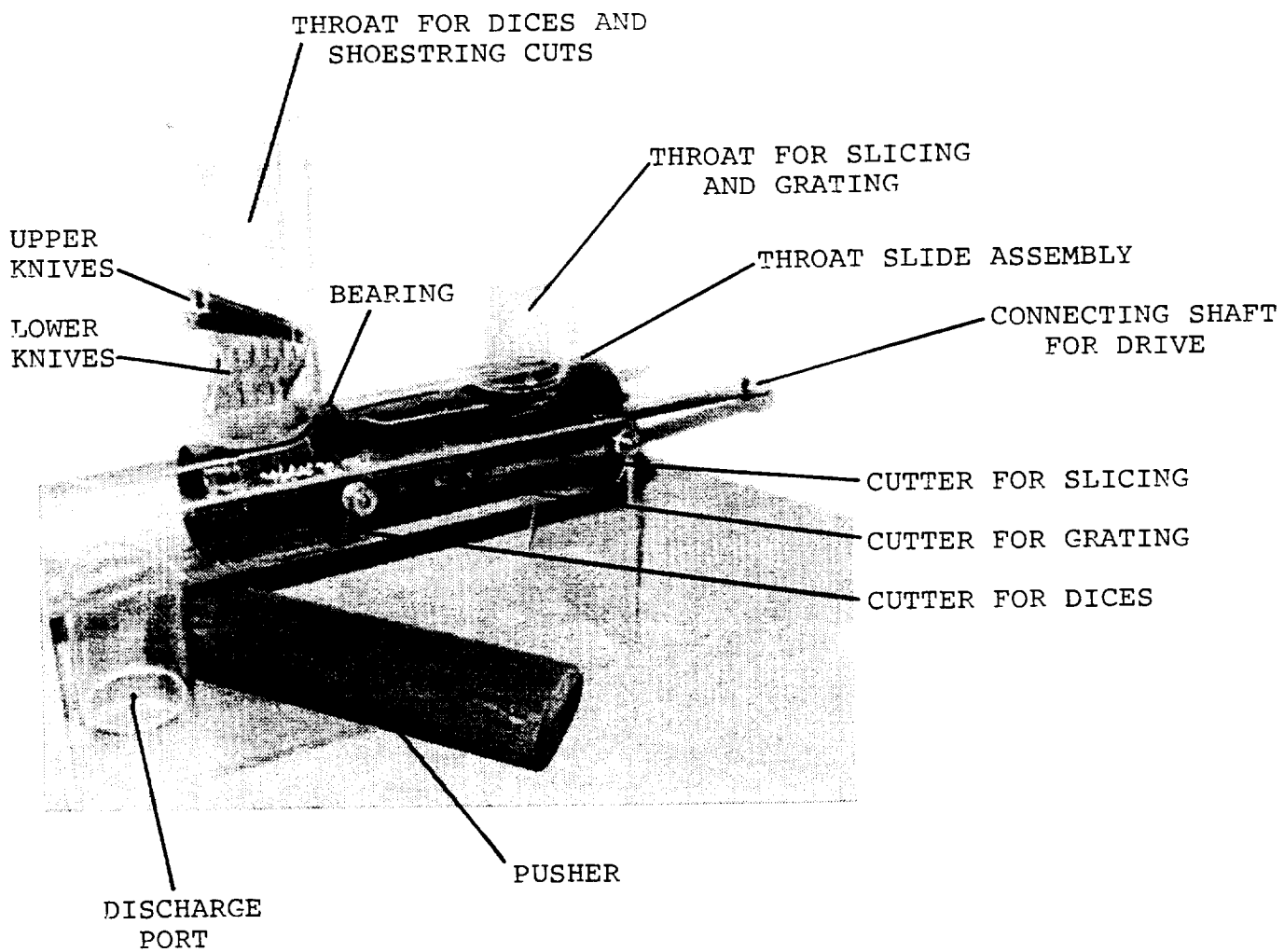
The design lends itself to "clean-in-place" washing. The wash-down trial entailed connecting a shop vacuum to the outlet then manually spraying water down the two throats and the inside of the cylinder while rotating it. Connecting fixed nozzles for these three positions should work effectively. Small fragments and the residues of starches and sugar seemed to be adequately rinsed, but a more important concern would be to dislodge slices, dices, and large fragments that might remain. The kind of hangups observed may be more attributable to the rough edges of the prototype than to inherent design shortcomings.

Another important part of a clean-up would be drying, to immediately follow spraying. The goal would be to remove all free water as quickly as possible to prevent the growth of organisms.

The Cuisinart type of slicer was not evaluated because it did not seem as easily adaptable as the design described above for minimum handling and ease of cleaning. However, it is desirable to incorporate french fry cutting and dicing operations if possible. This is described in the next section. While this function was tried with both configurations, it appears to work adequately with the modified Cuisinart.

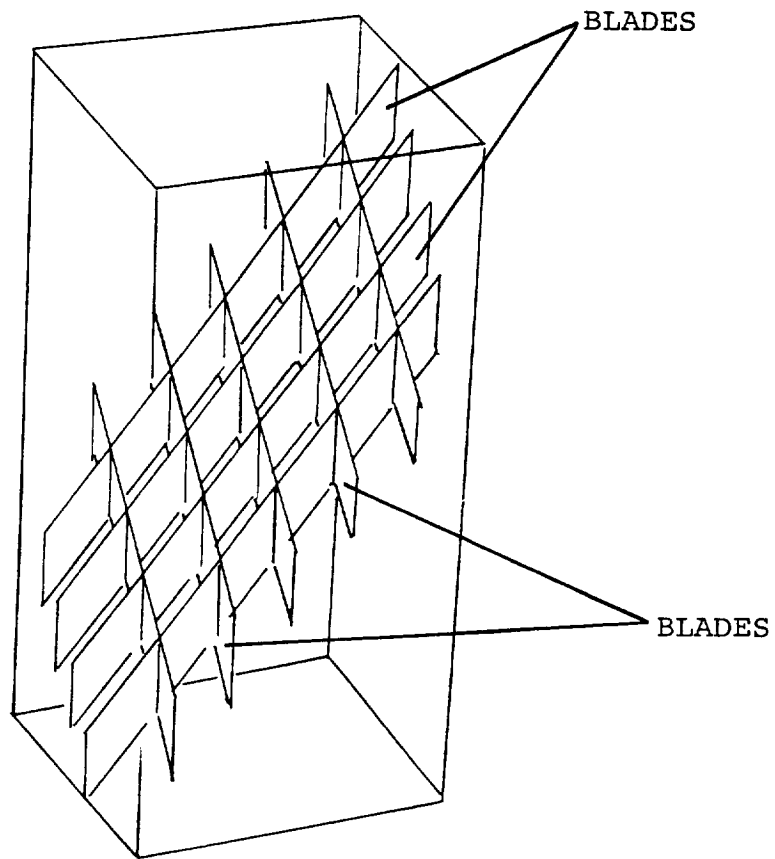
The Cuisinart design has much to recommend it, however, if the choice for overall food preparation equipment boils down to the choice of either one system or the other, but not both for the CELSS, then the K-Tec equipment would have the edge in attachment versatility, adequacy of power, and power to weight ratio. A number of minor modifications would, however, be necessary. These would include:

1. Provision to ensure positive collection of materials exit-



SLICER/GRATER/DICER/SHOESTRING
CUTTER PROTOTYPE

Figure 65



SHOESTRING CUTTER THROAT FOR SLICER/GRATER/DICER/
SHOESTRING CUTTER

Figure 66

- ing the cutter/grater head
2. Redesign of the head to reduce materials collecting between the cutter and cutter housing
 3. Redesign of the cutter/grater head to facilitate cleaning
 4. Provision for efficient storage of attachments
 5. Addition of a food processor drive

LIQUID MEASURING DEVICE

To provide easy and reliable, positive control in the measuring and handling of liquids under zero-gravity, syringes will be used. Figure 67 shows a syringe and manifold system for measuring and combining a series of liquid ingredients. In operation, an initial vacuum is pulled on the manifold by way of the exit port to minimize entrapped air, and the exit valve closed. Ingredients are drawn into the syringe by opening the desired ingredient valve and slowly withdrawing the piston for the amount of liquid needed. The ingredient valve would then be closed. When the full mix is complete, the syringe would be connected to the destination vessel, the exit valve would be opened and the piston advanced to discharge the liquid mixture.

The manifold illustrated in the figure shows an array of four ingredients; however, the manifold could be expanded to include as many as necessary.

ASPIRATOR TRAY TABLE

The key to traying operation would be the tray table, which would consist of a honey comb structure mounted over a plenum connected to the suction side of a small blower as shown in Figure 68. During the loading operation, an empty tray would be placed on the table. These trays would be constructed of fine screen over a metal frame, with a tightly-fitting separate screen lid to maintain product control.

Large particles, such as baked goods for proofing could be placed, in their pans, manually with clips or magnets to hold the pans in position. For small particles more positive control would be needed. A clear plastic glove-box lid would be placed on top of the tray, the aspirator hose connected at the top, and the blower started. To load the tray, the aspirator hose nozzle would be inserted into the bulkhead bin, sucking the particles over into the glovebox and onto the tray. When the tray was full, a gate valve could close off the aspirator hose. A lid would be inserted into the glovebox on top of the tray and fastened in place. The filled tray could then be removed from the table and inserted in the dryer or incubator, or wherever it was supposed to go. An empty tray would be placed on the aspirator table, and the gate valve to the aspirator hose reopened to start filling the second tray.

BIN STORAGE SYSTEM

Efficiently designed storage bins will have to achieve a number

CELSS Combination Liquid Measuring Device

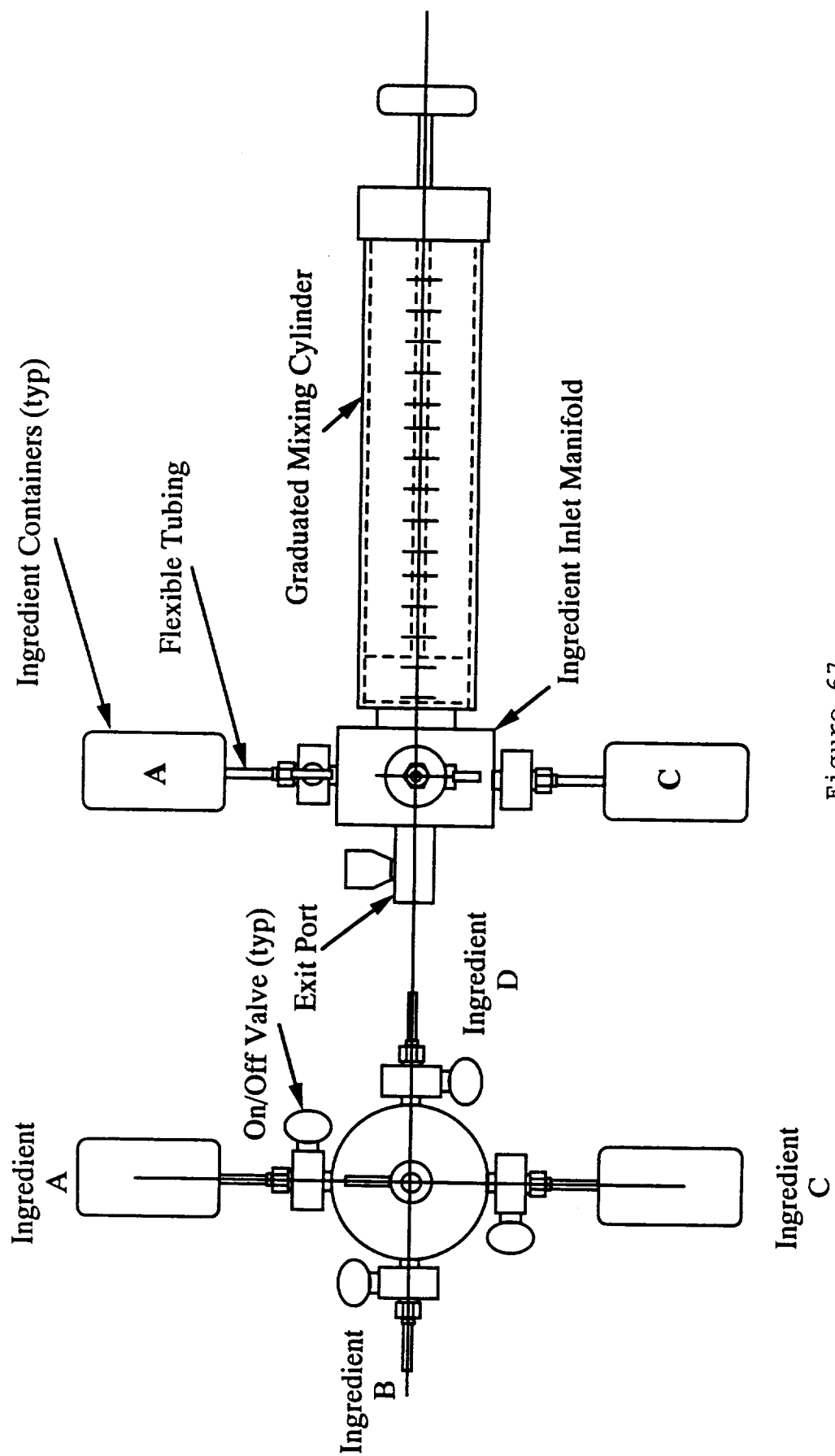


Figure 67

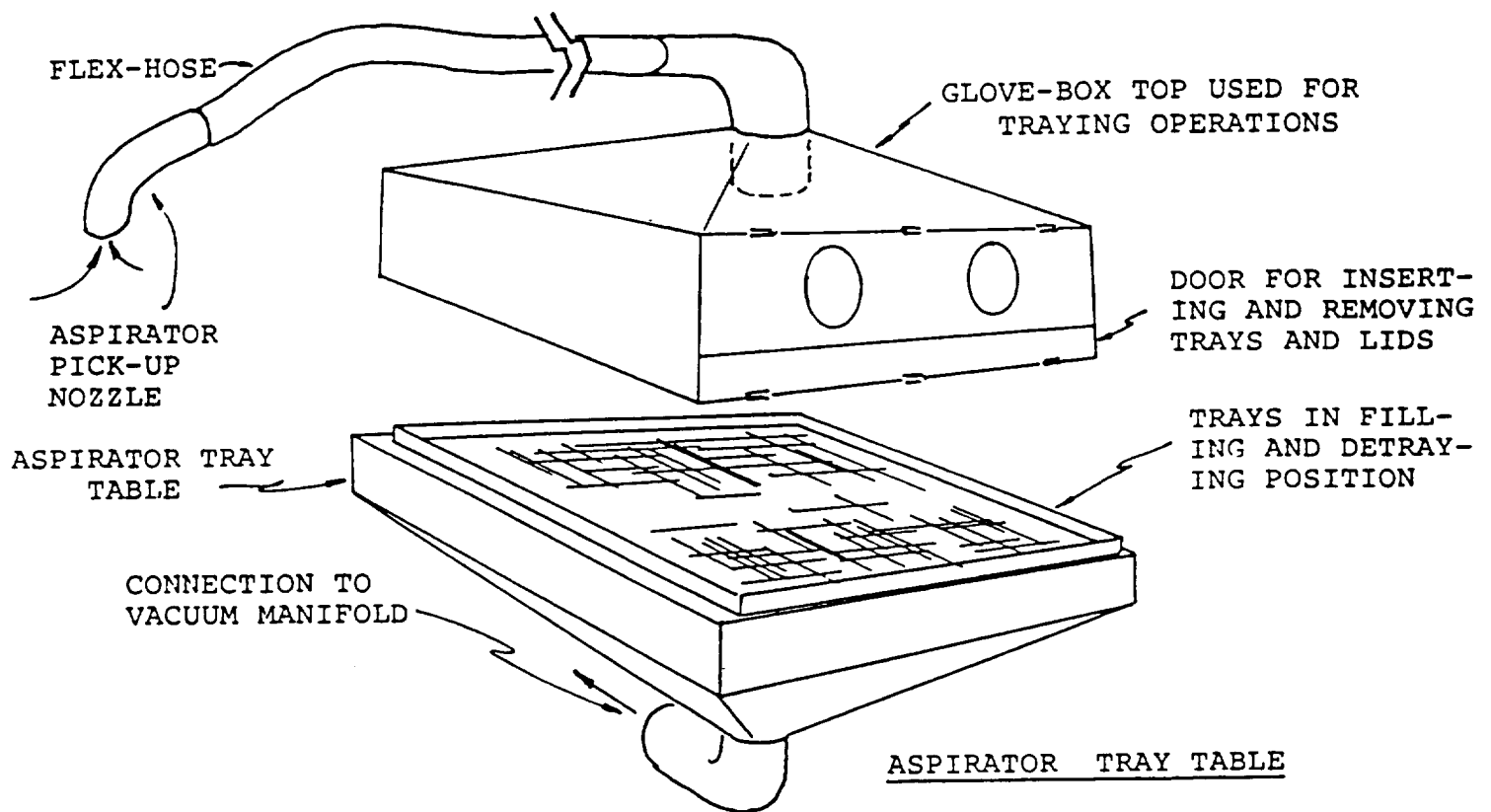


Figure 68

of important goals, including: ventilation to minimize spoil-age, minimum space utilization, ready access, effective particle control, and minimum intrusion into work spaces. Figures 69 and 70 employ the same basic concepts but illustrate two configurations in terms of fitting into CELSS spaces. It may be that both would be used. The lids of the Figure 69 design would serve as a counter or worktable surface in their closed position. The Figure 70 configuration is designed to be built into a bulkhead, tilted out as needed. Both concepts use perforated metal, cloth, or scintered metal bottoms or inserts and a vacuum plenum to provide adequate air flow for ventilation and particle control.

SIZE CLASSIFICATION/SEPARATION SYSTEM FOR DRY PARTICULATES

Figure 71 is a sketch of a screening device for classifying/separating dry flowable particulates by size. Specific applications within the CELSS program might include preliminary separation of soybeans and wheat berries from their respective plant waste. In operation, the device is based on a standard vibratory feeder base actuating a screen. These units require "gravity" to function. In zero-gravity applications the "gravity" would be provided by a laminar air flow directed as shown, which would push sufficiently small particles through the mesh, and hold larger particles against the screen so they would migrate towards the discharge. In the case of this specific application with soy and wheat, as the pod and chaff materials retained on the screen reached the discharge, they would be aspirated over to biomass processing, while the smaller beans would pass through the screen and be aspirated on to additional cleaning or processing.

The figure shows an approximate 8 mm mesh screen, however, this would need to be experimentally determined. Eight millimeter mesh may be adequate for soy, but would be much too large for wheat. As beans and wheat berries exit the screen, they would be aspirated to a receiver container for direct use or packaging and storage. Depending on the size of the unit, aspiration may not be sufficiently positive to collect the beans and berries from remote corners. Accordingly the bottom surface is angled and configured to work in concert with the vibratory motion. If angle A is larger than angle B, the step form of the sloped bottom should act on the return stroke to impel particles toward the discharge.

BIOMASS PROCESSING

Two principal fractions will be yielded by each of the crops that are cultivated in the CELSS environment - edible commodities, modities (wheat, soybeans, white potatoes, and sweet potatoes) and biomass. Biomass is defined as all the plant tissue matter (leaves, stems, vines, stalks, roots, etc.) which are not directly consumed by the CELSS crew. The value of the biomass for the CELSS program can be realized through combustion to attain carbon dioxide, water vapor, ash, and heat energy or as a substrate for the generation of edible food materials, such as mushrooms.

Dry Storage Bins

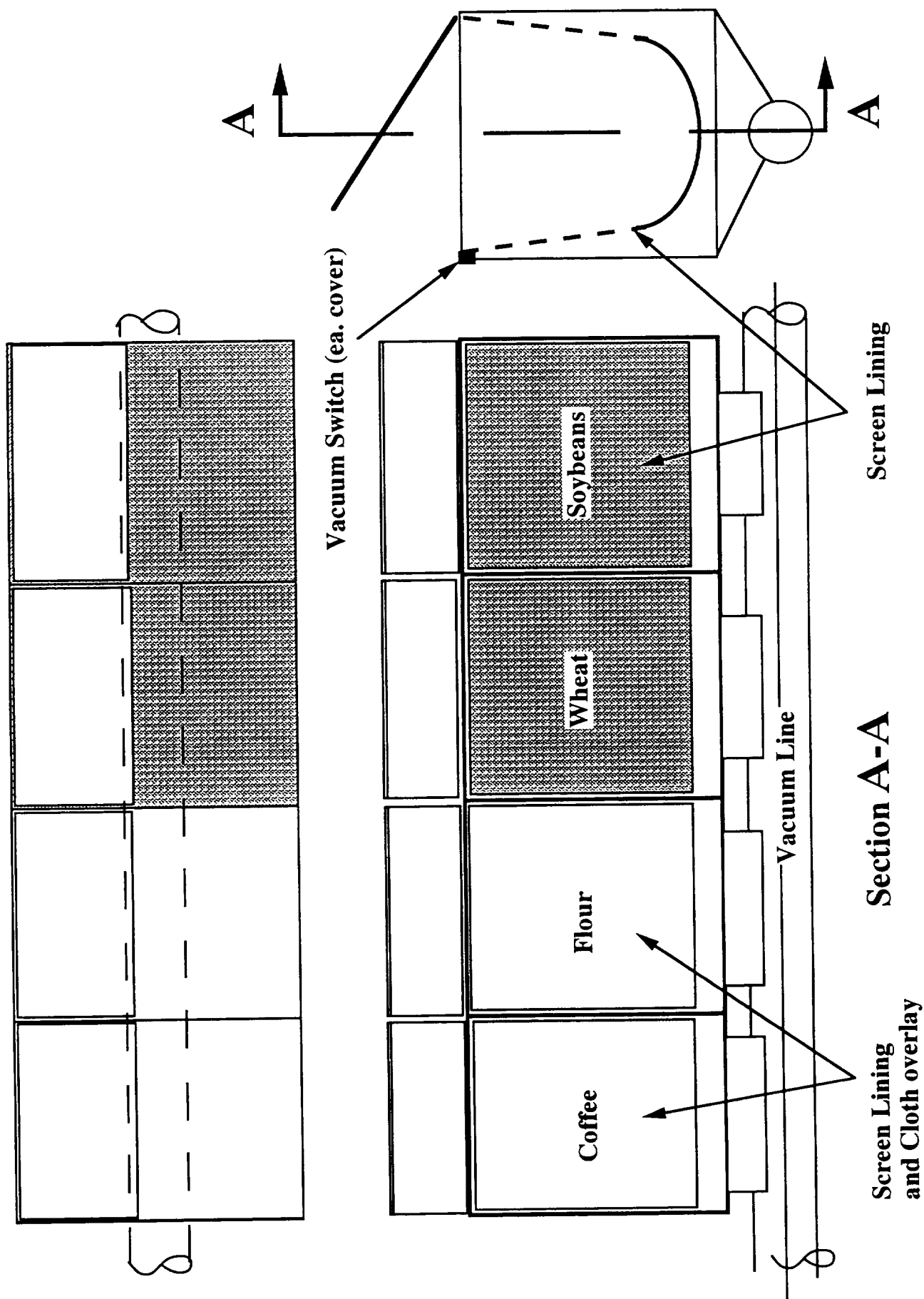
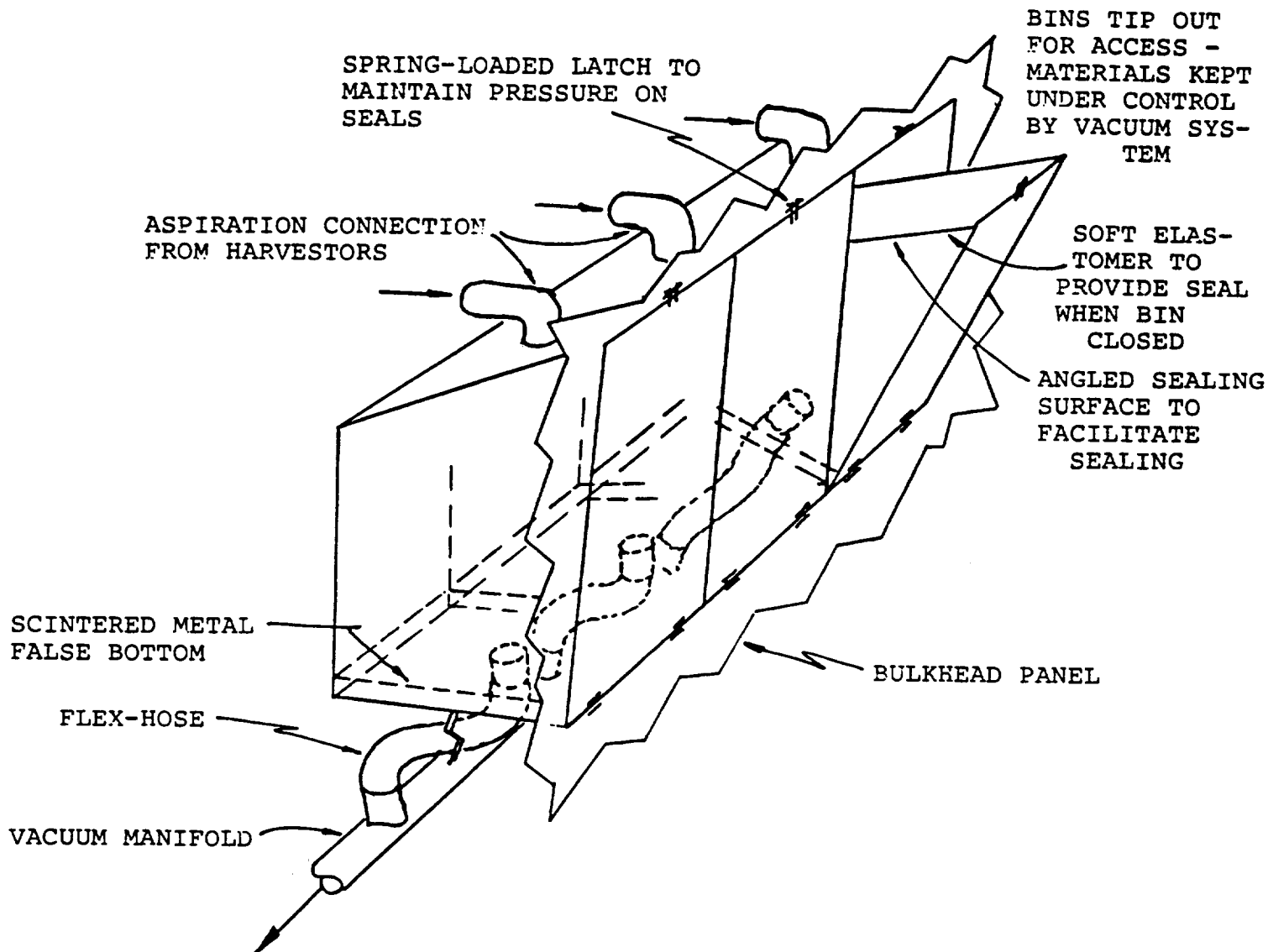
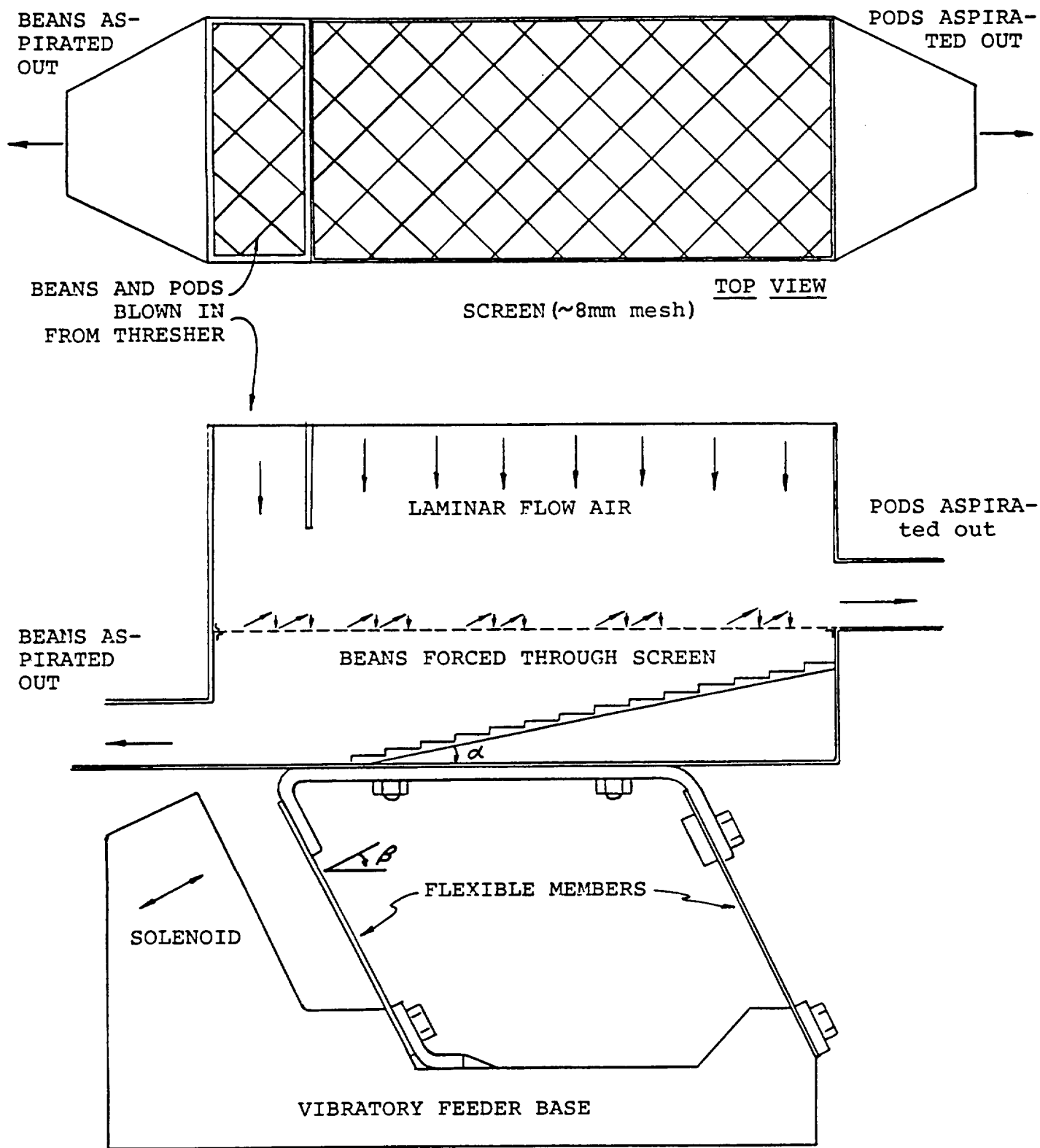


Figure 69



BULKHEAD BIN CONCEPT DESIGN

Figure 70



SIZE CLASSIFIER/SEPARATOR FOR BEANS AND WHEAT

Figure 71

7. Mushroom Primordia Formation and Cropping Growth Chamber
FASI has not taken the mushroom production system concept further than visualizing a work station with the glove box acting as a "hub" for the six associated chambers. The following discussion presents the integration of the chambers with the glove box to achieve a working culture system.

THE GLOVE BOX WORK STATION:

This glove box unit would be a one- or two-person work station with a design very similar to a laminar flow hood used in commercial mushroom or microbiological activities. The front of the hood would have clear doors which could be opened, as needed, for work to clean and sterilize the surfaces of the glove box area. Once a first level of cleaning and sanitizing is completed, closure of the glovebox and a final sterilizing with a bacteriostat could be accomplished with the glove capabilities.

The hood would consist of a HEPA (High Efficiency Particulate Air) filtered air inlet and a multistage filter outlet for the air used within the glove box and the growth chambers. There would be capabilities to divide the glove box into two separate work areas so that one operator could be working with straw preparation or culturing mycelium or spawn while a second operator could be working with a vegetative culture or harvesting of mushrooms from a cropping culture.

The design of the work station would be such that the six chambers involved with the mushroom production system would be built adjacent to the side and rear walls of the glove box unit, with doors separating these chambers from the glove box built into the walls of the glove box. The operator(s) would control which chambers would be opened and worked with from within the glove box. Controls for operation of the various chambers would be located within the glovebox or on external panels, depending on the need.

STRAW COLLECTION CHAMBER

This chamber is the endpoint for the separation of the wheat straw from the wheat berries at the point of harvest. It is anticipated by FASI that the separated straw will be at least coarsely chopped at the point of harvest and pneumatically conveyed from the harvest area to the mushroom production system. The straw collection chamber is built adjacent to the glove box work station for access from within the glove box.

Culture of the oyster mushroom is accomplished with coarsely chopped straw and FASI anticipates that this will be sufficiently accomplished in the wheat harvest operation. No other special design requirements are anticipated for this chamber, it is simply a collection reservoir from a cyclone separator in the air-veyor system.

The bulk of the biomass material is generated in the harvest operations for each of the crops grown. At the point of peak commodity nutritional development for each crop grown, a harvest operation will separate the directly edible commodity from the bulk of the crop tissue. The commodity, such as wheat heads or soybean pods, are sent to the Pre-Preparation Area for drying prior to threshing and separation of the wheat berries and soybeans from the chaff/pod fragments. The remainder of the plant tissue is coarsely chopped in the Harvest Area and aspirated to the Biomass Area for further processing. Chaff from the Pre-Preparation area and waste material from the Processing Area are also sent to biomass. Both potato crops provide biomass at the harvest operation.

Given harvest indices of 50% for Wheat (Bugbee), 55% for Soybeans (Raper), 80% for White Potatoes (Tibbetts), and 80% for Sweet Potatoes (Tibbetts), an estimated 7,786 gm of biomass will be produced each day. Assuming an average bulk density of 300 gm/L for the chopped biomass, the following volumes of material must be considered for storage purposes: Wheat, 13.6 L; Soybeans, 9.5 L; White Potatoes, 6.1 L; and Sweet Potatoes, 3.25 L. Since these materials could be moist, with some free liquid possibly occurring as a result of tissue cell disruption from chopping operations, fermentation and spoilage could happen quickly without further processing. Thus, any storage for this freshly chopped biomass must be considered transient surge collection rather than longer-term holding to accumulate material. Biomass processing would need to be a daily operation.

Biomass processing is summarized in Figure 72. The four crops yield four streams of biomass which feed two primary biomass processes: combustion and mushroom production. Biomass from the wheat harvest can be used for either mushroom production or the combustion process while biomass material from the other three crops would be directed solely to the combustion process. A discussion of these two processes follows.

BIOMASS PROCESSING FOR COMBUSTION

The simplest of the two processes, biomass processing for combustion would consist of a size reduction step, followed by drying, and completed with a milling step to produce a powdered biomass material ready for direct feeding into the combustor.

PARTICLE SIZE REDUCTION

Materials to be combusted, which includes all white potato and soybean biomass, the stems and root material from sweet potatoes, and wheat biomass on a periodic basis, would require drying to an optimum water content for proper combustion (anticipated to be 2 to 4% moisture). Once dried, the biomass will then need to be milled to an appropriate particle size for complete combustion.

As received from the choppers at the harvesting stations, the maximum particle sizes could range on the order of 2 to 3 cm.

Biomass Processing

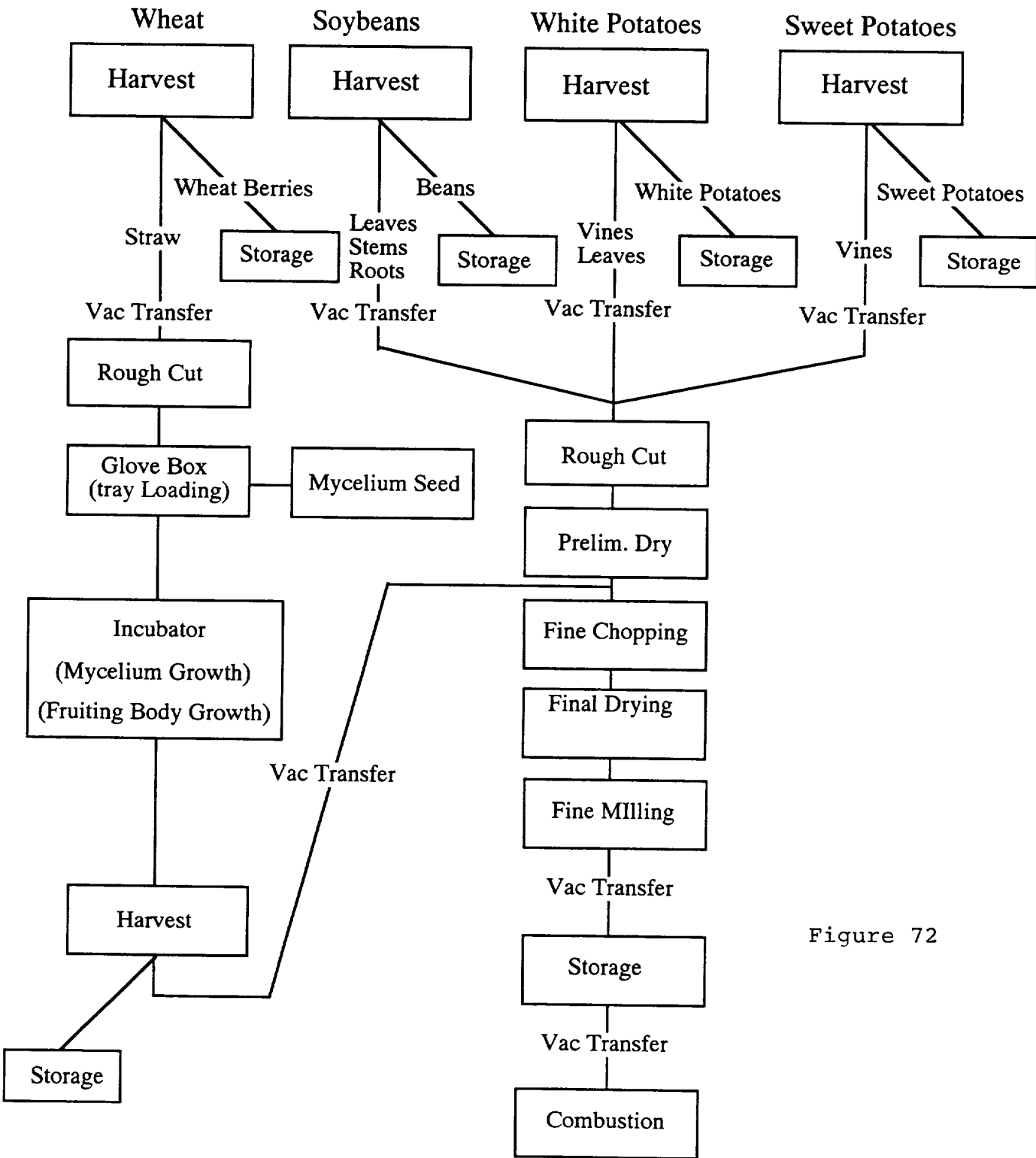


Figure 72

This size is not crucial. The objective would be to reduce the stem, vine and root material to a size that would not create bridging problems in the aspiration system.

To facilitate drying, it would be desirable to reduce the particle size of the chopped biomass to increase the surface area per unit volume of mass and to create a higher percentage of disrupted plant cells such that water vapor transfer is greatly increased. The objective in this additional chopping operation would be to reduce particle size without releasing so much tissue fluid that a hard-to-handle sludge would be created.

Two alternative types of cutters have been considered:

BIOMASS CHOPPER

Figure 73 shows a chopper designed to minimize creation of juice and fines. The cutters would be self-sharpening carbide discs, operating similarly to slitter rolls or a document shredder, but with jaw-like extensions to facilitate capture of larger particles such as chunks of stems, root masses, and runners. The open nature of the discs would permit aspiration of biomass material directly into the cutter jaws.

The exact moisture content of these materials at the point of mature-green harvest has not been established. Depending on the source, estimates range from in the range of 50% to as high as 70%, this latter figure applying to harvesting soy-beans for use as a green vegetable (i.e., Edamame). For bio-mass purposes, If the moisture is significantly higher than anticipated, minimizing release of tissue fluids may require that chopping and drying be a two stage operation, with the biomass receiving an initial coarse chop and partial drying, followed by a fine chop and final drying prior to fine milling. These coarse and fine choppers would be essentially the same design as Figure 74 except that the cutters would be thinner, perhaps 1.25 cm thick for the coarse cutter, and perhaps 0.5 cm or less for the fine unit.

An alternative to the document shredder-type chopper described above could be a device similar to a very slightly modified Cuisinart using the standard, backward-curved chopper blade. The standard Cuisinart does not work satisfactorily in chopping the hard stalks of wheat or the dry shells of soybeans. Observation indicates that wheat straw in particular, tends to wedge between the tip of the blade and the wall of the bowl. While the straw will bend at the point where the blade contacts it, it will not be cut unless the blade is particularly sharp. Enough uncut straws accumulate to bridge the gap between the blade tip and the side of the bowl. Without sufficient friction against the bowl wall to hold the straw, the accumulated mass is simply swept around with the blade, eventually building up considerable friction-generated heat on the bowl wall. The modification to prevent the choking described, consists of adding a very small anvil bar to the periphery of the bowl slightly above the top blade. Only one appears necessary because the lower blade sweeps so close to the bottom of the

Biomass Chopper

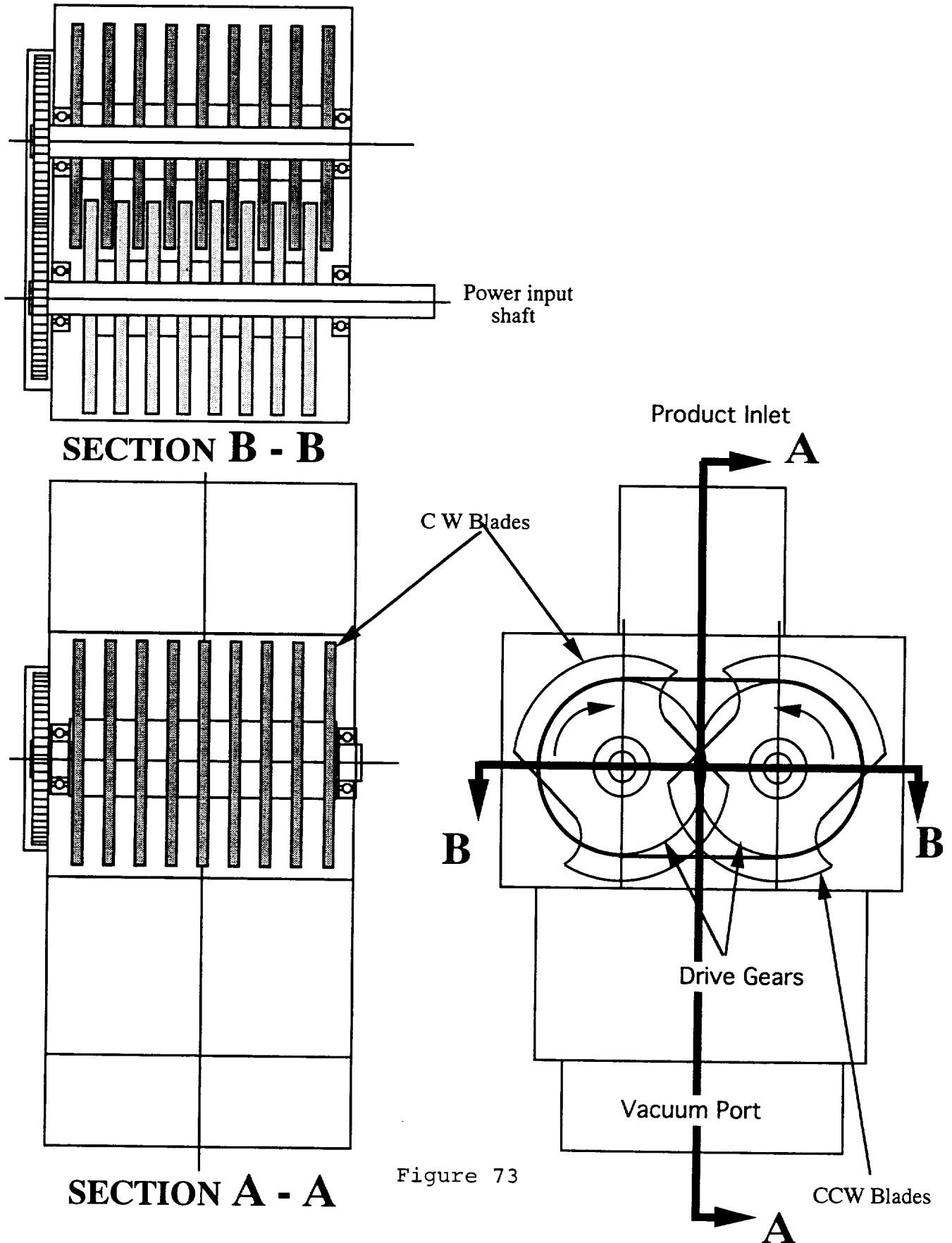


Figure 73

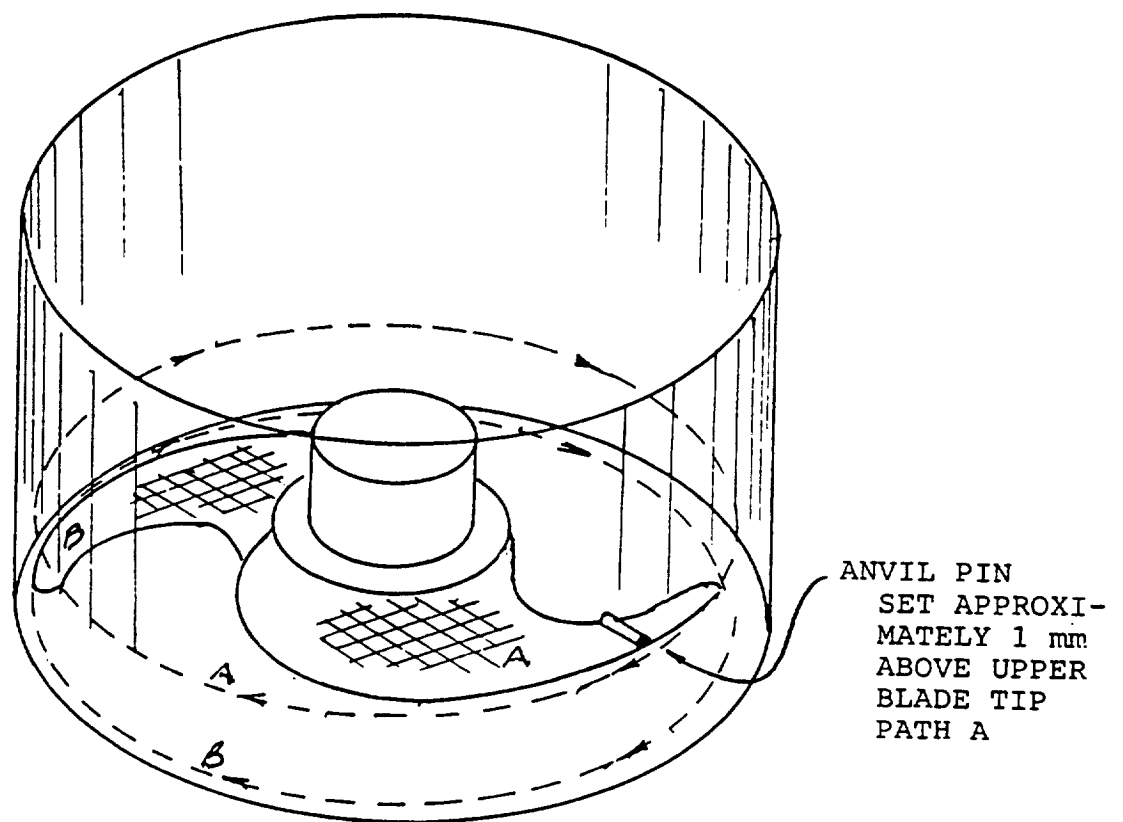
bowl, that material has far less tendency to bridge. The anvil for this initial test consisted of a metal peg, about 1 mm diameter, inserted radially through the cutter bowl just above the path of the top knife blade, see Figure 74. The effect of the anvil is to break wheat straw into pieces no longer than 1 cm in length in about 1 minute. Longer exposure results in further chopping, but at significantly diminished rates.

Dry soybean pods are very light, and although they tend to bridge less than wheat in the absence of an anvil, the draft caused by the blade motion causes the shells to assume a high peripheral velocity. The result is a less than normal differential velocity between the shells and blade to accomplish the cutting. The presence of an anvil tends to slow down the motion of the pods, and improves the size reduction. One minute of cutting reduces the pods to sections less than 0.2 cm². There is also a considerable portion that is pulverized to dust. Two minutes of cutting provides noticeably finer material, moreso than with wheat chaff, but two minutes is also close to a point of diminishing returns.

This approach has both advantages and disadvantages. In terms of advantages, it is both simple and versatile, and it could obviate the need for a dedicated unit for chopping biomass, though for scheduling and toxicity considerations, it may be desirable to opt for the dedicated unit and hard pipe it in. On the negative side, it is a batch/continuous batch process that would require an operator or robotics/instrumentation specialist that could be more or less dedicated given the amount and scheduling of biomass to be processed.

Under these circumstances, either a continuous, single-pass chopper or a Cuisinart-type cutter instrumented for continuous batch operation would appear suitable. The choice would depend on the whether fines would constitute a problem, and the weight/cube penalties these alternatives would entail. Unfortunately, during the course of the trials it was only possible to test with fully field dried wheat. In actual operation, the cutter/chopper would be handling leaf, stem and root material from potatoes, soybeans, and wheat as well as runner and root material from sweet potato harvested at the mature green stage. Unlike brittle, field dried material, most of the mature-green biomass might have a moisture content on the order of 50 percent. Because of its woody nature, sweet potatoes may be somewhat lower, but its fibers are very tough and could pose problems in term of jamming equipment or winding around shafts.

A typical scenario for processing biomass for combustion in the continuous batch mode involves aspiration of part or all of the biomass in the receiving bin to the secondary chopper described above, which produces a finely chopped output. Under normal circumstances, it is anticipated that the moisture level of the biomass would be such that the chopping operation could take place in one step without creating a mush-like output for feeding into the dryer. This might require appropriate blending of the coarsely chopped biomass materials in the receiving bins for moisture equilibration prior to chopping, or blending of



CUISINART-BASED BIOMASS CHOPPER

Figure 74

lower moisture stalk-type biomass with a higher moisture leaf-type material to minimize juice expulsion by desorption/absorption mechanisms during the chopping process.

However, if the moisture is significantly higher than anticipated, a two step chop-and-dry process may need to be used. This would require an intermediate-sized chopper having a 150% larger spacing (say 1.25 cm) than the equivalent design fine chopper at, say, 0.50 cm. Between the chopping operations, the resultant biomass would be fed into the drying operation for moisture removal. The characteristics of this dryer are explained below.

Experimentation during the earlier CELSS missions may show that a more efficient approach to utilizing biomass prior to incineration exists. This may include removal of plant nutrients from the biomass by extraction; the intent being to optimize utilization of the biomass nutrients in the closed system of CELSS. Although FASI describes the extraction process below, it is anticipated that such an approach would not be considered until at least a second-generation CELSS system is adapted.

To accomplish a suitable water extraction of the plant nutrients from wheat straw, it is anticipated that 1 Kg of biomass would require approximately 10 liters of water in an extraction process for 0.5-1.0 hours at 50-60°C. with mild agitation. Visualized is a jacketed inflatable vessel into which the coarsely chopped biomass would be charged, followed by the appropriate amount of water at the prescribed temperature. Water in the jacketed bladder would maintain the temperature and support the vessel while agitation is provided by mechanical peristaltic action on the outer walls of the vessel. The components (solids and liquid) would be separated by draining the liquid from the vessel through simply squeezing the vessel.

An alternative approach might employ a continuous pressing technique similar, but on a slightly larger scale, to the presses used in the natural foods industry for producing wheat grass juice. These units generally involve a tapered screw and screen, and may also use an adjustable screw at the tapered end to further increase the pressure exerted on the pulp. These units are frequently hand crank units, but could be designed to operate from a power pak. Preliminary trials of this approach performed in Phase I of this contract showed that very effective pressing could be accomplished with a 300 to 500 watts drive, given a properly designed press unit.

The continuous pressing technique could, as desired, be used directly on the incoming biomass or, as discussed above, on water extracted material. By this approach, a presscake with a moisture content of about 40 to 45 % might be achievable.

Liquid from the extraction process would be pumped through a filter and on to a membrane processing operation which would separate the plant nutrients from known plant growth inhibitors found in the vegetative biomass, as discussed in NASA Technical Memorandum 103497: Utilization of the Water Soluble Frac-

tion of Wheat Straw as a Plant Nutrient Source. The separated plant nutrient solution would then be concentrated to an appropriate level for direct usage in the growing area via reverse osmosis. Sludge material from filtration and the ultrafiltration concentrate containing the known plant growth inhibitor would be transferred to biomass incineration. The water permeate from the reverse osmosis system would be fed back into the extraction process. As the sophistication of CELSS operations grows, this extraction process could occur for all crop biomass prior to combustion to capture the plant nutrients in a soluble and readily reusable form.

DRYING

Several possible approaches are available for drying. In the interest of minimizing labor, it would be desirable to use a design which would have a high efficiency, good drying uniformity and a system which could be loaded and discharged automatically. Based on these characteristics, a "Jetstream-type dryer, described earlier in this report in the section on DRYER/THRESHER could be highly effective. Very generally, this is a louver-type of dryer, which utilizes high air velocity and a high degree of particle movement to achieve high drying rates. Depending on how they are designed, these units can operate either as continuous or batch dryers.

Figure 75 shows a system based on batch operation. In this system, material from the collection bin would be admitted into the dryer through the slide-gate valve, and would be caught up in the rapidly circulating air stream. When sensors detected that the moisture remaining in the material had fallen to the desired level, a discharge gate in the periphery of the dryer deck would open, discharging the material into a metering device feeding the mill.

For continuous operation, the dryer would operate similar to the upper portion of a cyclone. Lighter, dry particles would exit the chamber with the exhaust air through the outlet plenum, but the heavier, wetter particles will be retained in the chamber by centrifugal force until they become lighter and dry. The rate of exhaust air removal can be adjusted by the size of the outlet plenum.

In a typical dryer installation, exhaust air is recirculated. The exhaust air is laden with moisture; to maintain drying efficiency, a portion of the air is vented to the atmosphere and replaced with fresh, dry make-up air. How much air to recirculate is dependent on drying temperature and air saturation temperature, which varies with the product dried. Although there should be a theoretical ideal exchange proportion, very few drying operations are based on such a theoretical optimum; instead, rely on empirical data.

For CELSS space application, batch drying operations will most likely be preferred to continuous drying because of the small quantities of material being dried. Other important factors in the batch drying decision include the maintenance of the whole

PREPARATION OF BIOMASS FOR COMBUSTION

Figure 1

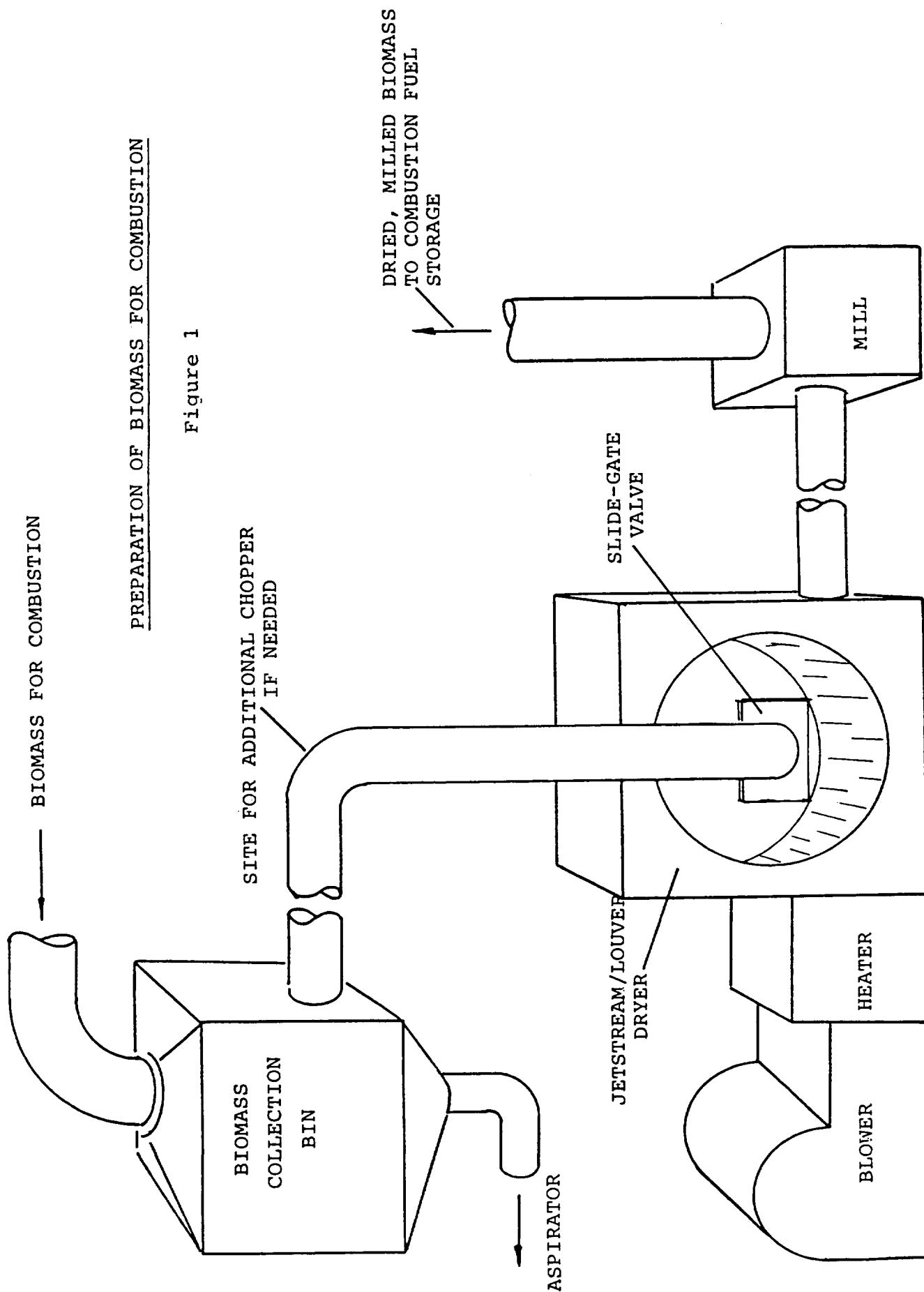


Figure 75

environment moisture balance and ease of material handling. The prototype constructed to simulate this drying concept is based on a once-through system with no air recirculation.

One factor adding to pressure requirements during prototype testing was gravity; which will be a minimal or nil factor for CELSS operation of this dryer. Zero-gravity should improve the loading characteristics of this design significantly.

It is anticipated that the combustor would provide a significant portion of the heat required for drying, though solar heat could possibly be used as well. The drying cycle would be measured by sensors monitoring the moisture in the intake and exhaust air. When the moisture level in the exhaust air approaches that of the inlet air (minimal addition of moisture to the air in the drying chamber) corresponding to a given biomass moisture, the dryer contents would be discharged, as previously described. Material circulating in the dryer would be aspirated over to the milling operation.

MILLING

Without more information about the combustor system, it is difficult to estimate the degree of milling needed. Certainly, in the interest of labor savings, it would be desirable to utilize a unit which could be loaded and discharged automatically. Based on preliminary milling trials conducted with a small impact coffee mill, a similar but larger unit should be entirely suitable. Such a unit should be able to accommodate the entire charge from the dryer, and might consist of a chamber approximately 0.5 M in diameter and 0.4 M high. The impeller and chamber would be configured to foster a strong vortex to circulate particles rapidly during milling. Typically, milling wheat berries and coffee beans at one-G requires 15-30 seconds; the biomass particles would be somewhat smaller and more fragile, and may require estimated intervals of 10 to 15 seconds. It is estimated that zero-gravity operation will result in much more efficient particle circulation, thus greater milling efficiency.

Other mills suitable for this application could include small, light weight units such as the K-Tec, described earlier in the report for use in milling flour. Other alternatives commonly used by industry for milling materials from drying operations frequently involve hammer mills. The choice would involve the degree of fineness required for combustion.

On completion of the milling operation, the biomass powder would be aspirated to a bin feeding the combustor unit.

BIOMASS CULTURE OF MUSHROOMS

A second approach for utilization of biomass material is to produce mushrooms as a directly-consumable food component for the crew of CELSS. Mushrooms will serve to add a difference in flavor and texture to a number of the menu items prepared for the astronauts. Certain nutritional value will be gained from this food

ingredient as well. The crew will benefit from the addition of mushrooms as main ingredients and flavor enhancers in soups, as part of the ingredients in a hot, main-course entrees, or as a garnish on salads. Nutritionally, mushrooms compare favorably with most fresh vegetables in protein levels and are a good sources of such vitamins and minerals as riboflavin, niacin, pantothenic acid, iron and copper.

For mushroom production to be compatible with space environments, the mushroom culture process must be made as simple as possible. The object, unlike commercial mushroom production, would not be to maximize yield from the substrate or to convert every pinhead developed to a viable mushroom, but to convert a portion of the inedible biomass to a food substance for variety in the astronaut's diet and to gain some nutritional benefit from the constituents in the inedible biomass. FASI believes that there are two major components to the simplified success with mushroom production aboard CELSS:

1. The Mushroom Species Selected
2. The Mushroom Production System

MUSHROOM SPECIES:

As presented above, the culture of mushrooms is a complex sequence of steps, each stage having critical factors which impact on the total results of the mushroom set. A major consideration for CELSS production of mushrooms is the species of mushroom selected. In selecting a species of mushroom for culture aboard CELSS, FASI believes that the most critical factor is that the substrate material need not be composted. Secondly, eliminating the casing layer would seem desirable. Finally, the tolerance for carbon dioxide would seem to be important in minimizing the number of air changes in the growth chamber, thus minimizing the power required to culture mushrooms. Given these targets, an examination of the potential varieties of mushroom is presented in this section.

In review of the various species of mushrooms, there are four species that are capable of growing on un-composted, pasteurized straw; these species are: Paneolus cyanescens, Pleurotus ostreatus, Psilocybe cubensis, and Stropharia rugoso-annulata. The array of specifications characterizing the various stages of culture for each of these mushrooms is shown in Table 6. Given that each of these species can be grown on pasteurized straw, the secondary criteria regarding the casing layer requirement clearly sets the Pleurotus ostreatus (oyster mushroom) apart from the others; the oyster mushroom does not require a casing layer, it can fruit from a single-component substrate.

With further review of the oyster mushroom characteristics in Table 6, it is found to be a very efficient user of substrate nutrients and is said to produce abundant crops in a short period of time. One distinct advantage that FASI believes is very useful for mushroom culture aboard CELSS is that this mushroom variety can be grown with "plastic bag culture". This will be further discussed below, but FASI believes this is a useful, con-

	PANEOIUS CYANESCENS	PLEUROTUS OSTREATUS	PSILOCYBE CUBENSIS	STROPHARIA RUGOSO-ANNULATA
Primordia Formation: Relative Humidity Air Temp. Carbon Dioxide Fresh Air Exchg. Light Req. Duration	95 + % 75-80°F 5,000 ppm or less 2 per hour Fluorescent grow lights --	95% 55-60°F 4,600 ppm 4 per hour 2,000 lux/hr* 7-14 Days *12 hrs on/12 hrs. off	95-100% 74-78°F < 5,000 ppm 1-3 per hour 480 nm wave-length* 6-10 Days *12-16 hrs on; remainder off	95 + % 55-62°F < 1,000 ppm 2-4 per hour Grow-lux fluorescent* -- *12 hr. on cycle; remainder off
Cropping: Relative Humidity Air Temperature Carbon Dioxide Fresh Air Exchg. Harvest Stage Flushing Interval Light Req. Duration	85-92% 75-80°F 5,000 ppm or less 2 per hour Caps convex 5-7 Days Grow lights --	85-92% 60-64°F < 600 ppm 4-6 per hour Prior to elevating to plane 10 days 12 hrs. on/off cycle 5-7 Weeks	85-92% 74-78°F < 5,000 ppm 1-3 per hour When cap convex 5-8 Days 12-16 hrs. on/remainder off 5 Weeks	85-92% 55-62°F < 1,000 ppm 2-4 per hour Partial veil tears 10-15 days 12 hour on cycle 8 Weeks
Yield Potential	Not yet established	1 Kg fresh mushroom; per Kg, dry weigh of substrate	2-4 pounds sq. ft. cropping surface	2-3 pounds/ft. ²
Mushroom Specifications	90-92% Water 8-10% Dry Matter	91% Moisture 9% Dry Matter	92% Moisture 8% Dry Matter	92% Moisture 8% Dry Matter .22% Protein .34 mg Niacin 100 gm DM
Comments	<ul style="list-style-type: none"> •Rapidly Growing species •Fruits readily on straw (pasteurized) •Requires 1/2-inch casing layer •Fruiting bodies small (long narrow stems) •Flushes typically abundant 	<ul style="list-style-type: none"> •Regular misting 1-2 times daily until fruiting bodies 30-40 full size •Efficiently uses substrate •Ability to fruit a single-component substrate (no casing) •Produces abundant crops in short period of time 	<ul style="list-style-type: none"> •One of the most commonly cultivated mushrooms •Easy to grow •Fruits on wide variety of substrates w/in broad environ. parameters •Composited or un-composited substrate •Mushroom has psychoactive properties (psilocybin) 	<ul style="list-style-type: none"> •Regular mist water •1-2 daily during primordia formation •Grows well in colder climates •Wide range of temperature for fruiting

Table 6

Sources: The Mushroom Cultivator by Paul Stamets and J.S. Chilton, 1983; and Mushrooms of Western North America by R.T. and P.R. Arora

tained approach to growing mushrooms in a controlled environment growth chamber. Finally, the oyster mushroom is cultured at a relatively cool temperature, possibly requiring less energy demand during culture than other candidate mushroom species.

The drawbacks to the oyster mushroom are that it produces an abundant supply of spores and, if harvest is not timely, these can be a detriment to the growth of future flushes of fruiting bodies per mushroom set, can cause certain allergic reactions if inhaled, and can be a physical hazard in a CELSS environment. However, breeding research has produced a "low-sporeload" oyster mushroom variety (P-3 from the Swiss American Spawn Company) which may alleviate a great deal of this drawback. Also, the oyster mushroom seems to require more water addition as culture proceeds and is more sensitive to carbon dioxide presence in the fruiting and cropping stages than the other three varieties. FASI believes that these factors can be controlled within a properly designed growth chamber.

Not closing the door to other potential species of mushrooms and not saying that multiple species cultivation of mushrooms is not possible, FASI will continue this discussion by assuming that a single species culture program to include the oyster mushroom is part of the CELSS growth program to utilize inedible biomass to produce edible mushrooms. The species of mushroom will impact the types of hardware and growth chamber systems required, as presented below.

THE MUSHROOM PRODUCTION SYSTEM:

The mushroom production system or work station is key to the success of mushroom culture aboard CELSS. The initial portion of this discussion indicated quite close control of a number of variables is required at each stage of the culture process. In the early culture stages (Agar and grain culture), care to prevent cross-contamination is analogous to the requirements for microbiological culture. A clean environment and sterile transfer capabilities are necessary for successful results in these stages of activity. Spawn running and early fruitification stages of production require close control of a number of substrate and environmental factors that are different from the control levels during the cropping stages for many of these variables. Finally, reverse contamination of the CELSS environment with spores from mushroom culture is a significant concern. All these control requirements, plus the ability to meet our objective of a simplified mushroom culture process, falls on the design of the mushroom production system.

It is anticipated that the mushroom production system would consist of seven zones or areas of capability:

1. Glove Box Work Station
2. Straw Collection Chamber
3. Autoclave and Straw Pasteurization/Conditioning Chamber
4. Supplies Transfer Chamber
5. Agar/Grain Culture Growth Chamber
6. Mycelium Vegetative Growth Chamber

7. Mushroom Primordia Formation and Cropping Growth Chamber

FASI has not taken the mushroom production system concept further than visualizing a work station with the glove box acting as a "hub" for the six associated chambers. The following discussion presents the integration of the chambers with the glove box to achieve a working culture system.

THE GLOVE BOX WORK STATION:

This glove box unit would be a one- or two-person work station with a design very similar to a laminar flow hood used in commercial mushroom or microbiological activities. The front of the hood would have clear doors which could be opened, as needed, for work to clean and sterilize the surfaces of the glove box area. Once a first level of cleaning and sanitizing is completed, closure of the glovebox and a final sterilizing with a bacteriosat could be accomplished with the glove capabilities.

The hood would consist of a HEPA (High Efficiency Particulate Air) filtered air inlet and a multistage filter outlet for the air used within the glove box and the growth chambers. There would be capabilities to divide the glove box into two separate work areas so that one operator could be working with straw preparation or culturing mycelium or spawn while a second operator could be working with a vegetative culture or harvesting of mushrooms from a cropping culture.

The design of the work station would be such that the six chambers involved with the mushroom production system would be built adjacent to the side and rear walls of the glove box unit, with doors separating these chambers from the glove box built into the walls of the glove box. The operator(s) would control which chambers would be opened and worked with from within the glove box. Controls for operation of the various chambers would be located within the glovebox or on external panels, depending on the need.

STRAW COLLECTION CHAMBER

This chamber is the endpoint for the separation of the wheat straw from the wheat berries at the point of harvest. It is anticipated by FASI that the separated straw will be at least coarsely chopped at the point of harvest and pneumatically conveyed from the harvest area to the mushroom production system. The straw collection chamber is built adjacent to the glove box work station for access from within the glove box. Culture of the oyster mushroom is accomplished with coarsely chopped straw and FASI anticipates that this will be sufficiently accomplished in the wheat harvest operation. No other special design requirements are anticipated for this chamber, it is simply a collection reservoir from a cyclone separator in the airveyor system.

FASI has determined that approximately 13 Liters or 4 Kg of wheat straw will be accumulated each day from wheat harvest. The straw collection chamber design can be such as to handle one or multiple days accumulation of straw, depending on the overall mushroom culture program.

AUTOClave AND STRAW PASTEURIZATION/CONDITIONING CHAMBER

This chamber, most like constructed adjacent to the wheat straw collection chamber, will be a standard laboratory autoclave unit capable of steam pressure processing to 15 psig. The size and shape of the unit is open for review; a rectangular chamber would optimize the use of space. The size of the autoclave would be approximately 50 to 75 liters.

The autoclave chamber would be used for steam pasteurization of the straw, straw conditioning for growth of symbiotic microorganisms and moisture equilibration to the appropriate substrate level. Also, this autoclave would be used for media preparation for agar and grain culture, sterilization of the containers and utensils used with mushroom culture and sterilization of used cultures and substrates prior to removal from the mushroom production system.

This unit could contain a self-supply of steam from a steam generator or be plumbed into the CELSS steam supply (if such exists). Steam is important to this operation in that wet heat (as opposed to dry oven heat) is necessary to attain the "kills" of microorganisms, insects, pests, etc. required for this type of sterilization process.

SUPPLIES TRANSFER CHAMBER:

This chamber is simply a double-doored chamber lock into the glove box work station. This chamber is constructed exactly like the autoclave (and can be used as an autoclave, if needed), but has doors on both ends. Besides acting as an emergency autoclave, this chamber can be steam sterilized to act as a sterile lock between the glove box and the outside environment.

The primary purpose of this chamber is to act as a transfer and storage mechanism between the interior of the glove box and the outside environment for materials needed from the outside. While working in the glove box, operators must have easy access to the supplies and materials they need for their tasks. The supplies transfer chamber must provide easy access and use.

AGAR/GRAIN CULTURE GROWTH CHAMBER

The final three chambers in the mushroom production system are environmentally controlled growth chambers of varying sizes and capabilities. The first of these growth chambers (incubators) is used for the development of the agar and grain cultures used to initiate a given set of mushrooms. Temperature of the environment is the only variable that need be controlled in this chamber other than the cleanliness of the air in the chamber to minimize chances for contamination.

The agar/grain culture growth chamber need only be 10 to 20 L in capacity; its function being simply to hold a set of Petri dishes or a series of grain culture jars. Heat supplied to this growth chamber need only be sufficient to increase and maintain the temperature slightly above ambient conditions.

MYCELIUM VEGETATIVE GROWTH CHAMBER:

For the culture, fruitification and cropping of mushrooms, FASI would recommend two growth chambers. One chamber, the mycelium vegetative growth chamber, would be set for the conditions specific to spawn running throughout the substrate. Once the vegetative growth was completed, the culture would be moved into the second chamber, the primordia formation and mushroom cropping growth chamber, for completion of the culturing through harvest of the mushrooms. The advantage of the two-chamber concept is two-fold: control of the chamber environment does not need to be drastically shifted to "signal" the change from vegetative growth to fruitification, this is accomplished by moving the culture into a pre-established appropriate environment - the transition is essentially instant. Secondly, the dual environment will allow mushroom cultures to proceed in sequence with a vegetative culture ready to move into the cropping growth chamber once the preceding mushroom set has completed its productive flushes of mushrooms. Proper sequencing should allow a continuous supply of fresh mushrooms to be available for the astronauts food supply.

FASI anticipates that the oyster mushroom will be cultured in plastic bags aboard CELSS. The conditioned and pasteurized straw would be appropriately mixed with the optimum amount of grain culture inoculum and placed into an approximately 20-Liter plastic bag, which have been pre-punched with 25 to 30 vent holes estimated to be one centimeter in diameter. Compaction of the straw into the bags will be learned by practice to maximize the amount of substrate per given mushroom set while leaving the porosity optimal for transfer of gases and minimal heat buildup in the center of the substrate mass. The bag cultures are then placed into the mycelium vegetative growth chamber for spawn running. The chamber should be sized to hold two to four of these bag cultures; FASI estimates this to be approximately 100 to 150 liters in volume.

For mycelium vegetative growth, the principle culturing variables which need controlling are relative humidity and substrate temperature. Essentially, the substrate temperature must not approach 35°C or damage to the mycelium can occur; cropping yield certainly will be impaired. While controlling relative humidity in the chamber, the equipment must be prepared to dump in fresh air to the chamber to cool the substrate as metabolic heat builds with rapid mycelium growth. Carbon dioxide sensing should be available on this unit, although the oyster mushroom is not sensitive to carbon dioxide at this stage in the culturing process. Mycelium vegetative growth occurs in total darkness, thus light in this chamber is not a factor.

One other variable which may need to be considered for this chamber is the ability to mist water onto the substrate on a periodic basis. This is a factor in maintaining the relative humidity of the chamber environment and it is also critical that the moisture content of the substrate not be allowed to vary during this vegetative growth period.

MUSHROOM PRIMORDIA FORMATION AND CROPPING GROWTH CHAMBER:

The final section of the mushroom production system is the primordia formation and cropping growth chamber. FASI anticipates that this chamber will be identical in size and design to the vegetative growth chamber, differing only in the conditions that are controlled.

Although primordia formation and cropping are two different stages of the mushroom development process, the control of conditions is a relatively simple change to accomplish. While temperature control for the vegetative growth stage involved the substrate temperature, temperature control in the primordia and cropping stages simply involves the air temperature. Shifting between primordia formation and cropping temperatures is a simple 3 to 4°C upward adjustment, achieved in a relatively short time.

The other principle factor which needs to be adjusted between primordia formation and cropping conditions is relative humidity. There is a small drop in relative humidity required as the culture progresses from primordia formation to cropping. This change should be relatively simple in that the air temperature is elevated somewhat at this point and this will naturally drop the relative humidity. The difference can simply be made up with fresh air injection or misting of water into the chamber.

Given the small differences between primordia formation and cropping, it must be noted that significant changes are experienced between vegetative growth and primordia formation, thus the suggestion of changing growth chambers. Earlier we described how fruitification with the vegetative mycelium can and must be forced or too much vegetative growth will minimize the yield of crop from a given set of mushrooms. It is with the shift in several of the environmental conditions that this "nudge" toward fruitification is achieved. There is a significant drop in temperature (approximately 10 to 12°C) between vegetative growth environment and primordia formation. Also, a drastic lowering of the carbon dioxide concentration in the environment (from 20,000 ppm to less than 600 ppm) is necessary, requiring the capability of changing the air in the chamber from four to six times per hour. This puts a load on the temperature and humidity supply systems for this chamber; these conditioning units must be of significantly higher capacity than for the vegetative growth chamber to adjust for all the fresh air that must be admitted.

Light begins to play a part in the culture process during the primordia development and mushroom cropping stage. The oyster mushroom is phototropic and responds best to about 2000 lux per hour on a 12-hour-on, 12-hour-off cycle with artificial light, usually provided by grow-lux fluorescent lighting. This must be appropriately provided and controlled in the growth chamber. Finally, moisture is important to development of the fruiting bodies (immature mushrooms) up until they reach about 30 to 40% of full size (after that point water becomes a detriment in that disease and parasite growth can occur). Provisions for water addition must exist in the primordia formation and cropping growth chamber.

Once the vegetative growth is completed and the cultures are ready to move into the primordia formation and cropping growth chamber, the mycelium have completely grown within the substrate such that the plastic bag used to hold the substrate together can be removed. This will increase the cropping surface to all sides of the culture save that side which supports the mass. To control the particles which may occur in handling and moving the culture matrix, FASI suggests that the bagged culture from vegetative growth be placed into a growth cage prior to removal of the bag and entrance in to the primordia/cropping chamber.

WHEAT

EFFECT OF MATURE GREEN HARVESTING ON WHEAT PROCESSES/EQUIPMENT

A small amount of hard red winter wheat was grown to provide samples for testing. Examination of samples harvested at various stages of development indicated that berries continue to develop at least as long as there is any vestige of green color left in the head. Even at that point, however, the berries are somewhat soft and plastic, to the degree that shear forces could cause damage if they were involved in threshing. Impact forces of the type anticipated in the centrifugal dryer-thresher, may be much better tolerated.

Based on the degree of moisture remaining in the berry, it is apparent that additional drying will be needed, beyond that required for threshing, to prepare the berries for milling. This could be accomplished in the centrifugal (louver) dryer-thresher by extending the drying operation prior to threshing (which would also probably improve threshing efficiency), or could be done by allowing the berries to undergo a drying cycle on their own after threshing was complete, and the chaff, stems, and root structures had been removed. An alternative procedure could involve aspirating the berries to an aspirating/tray table where they could be placed in a tray and finish dried in a cabinet drier prior to milling. Either procedure should produce a suitable product. The principal determinant of choice would be demands on equipment and time, since the cabinet dryer may be somewhat slower than the centrifugal (louver) dryer.

Some very preliminary data based on these small samples were that the approximate bulk density of freshly harvested wheat heads, randomly oriented was about 78 gr./L. The bulk density of dry chaff was about 38 gm/L.

GLUTEN

Given the most likely crop candidates; wheat, white potatoes, soybeans, and sweet potatoes, the principal source of meat replacements would be soybeans, in the form of tempe and tofu. Both of these products are excellent in terms of nutrition and acceptability. FASI scientists have tried them in the form of

hamburgers, frankfurters, and "cutlets"; and during our recent Phase II program, have used them as toppings for pizzas and as ingredients in casseroles while evaluating oven performance. Despite soybean's excellent performance and versatility, menu fatigue could constitute a genuine hazard.

Wheat gluten would constitute a welcome and valuable addition as a meat replacement. Particular advantages of gluten include its chewy, resilient texture, which tends to imitate the mouth feel of meat, the comparative ease with which meat analogs can be manufactured from it, and its bland flavor. Depending on the product desired, production can be as easy as extruding or pressing a gluten dough into a thin sheet, setting it with heat, and then slicing it for use in stir-fry dishes, casseroles, sandwiches, or pizzas. Because of its bland flavor, minor additions enable it to mimic the flavor of chicken, pork, or beef.

The major impediment relating to gluten is the difficulty involved in isolating it. Two procedures are used commercially, wet milling, and air classification.

In the wet milling process, the wheat is dry milled, water is added to make a dough. Kneading is continued to develop the gluten while adding water. Gluten is a comparatively sticky material which tends to agglomerate, whereas the starch granules are not sticky and tend to elute out with the water stream. On completion of the process, the gluten and the starch (having settled out of the water suspension) are both dried.

The air classification process used in 1-G environments involves differential settling characteristics. Starch cells are essentially spheroids. Size ranges approximately 20 to 30 microns and density is approximately 1.57. Gluten particles are more wedge-shaped, range about 15 microns in size, and have a density of about 1.32. ABB company has developed a classifier that can be used to effect a satisfactory separation. Unfortunately, zero-gravity and size considerations would appear to preclude the use of air classification. The effect of reduced gravity needs to be investigated.

Effort should also be devoted to reviewing the specific parameters for separating gluten from starch in order to examine its technical feasibility for CELSS installations. Specific concerns to be studied should include methodology for reducing the amount of water required for starch elution, and techniques for starch recovery. The starch serves as a thickener and stabilizer because of its water binding properties. Gluten can be used as an ingredient in breads and other products, however, its major function is anticipated to be as a meat replacement.

Wheat cultivars currently under development for use in CELSS have protein content ranging 18 to 20 percent, and as high as 22 percent; contrasted with a normal semolina protein content of about 13 percent, a normal bread flour protein content of about 12 percent, and a standard flour protein content of about 11 percent.

With the development of reduced/microgravity-suitable tech-

nologies for gluten separation, it would be desirable to extract 20 percent of the gluten from a 20 to 25 percent protein wheat to obtain a flour for pasta production as well as a meat analog substrate, or to extract 40 percent of the protein from the wheat to make a flour for bread, cookies, and general baked goods production. The ability to partially extract gluten from the high protein wheat cultivars would contribute significantly to providing astronauts with varied and interesting menu.

Should wet milling and air classification prove incompatible with space operations, the alternative for adapting ultra high protein flours for production of normal baked goods applications, may be dilution. Possible concepts under consideration include growing low protein wheat cultivars to serve as diluents. This would require additional space and equipment for crop production and harvesting/processing. A more feasible alternative in terms of weight penalty and efficiency may be the use of other diluents, such as potato flour. While potato flour is occasionally mixed with wheat flour to produce breads and other baked goods such as doughnuts, with very acceptable results, its suitability in products such as pasta would need to be investigated.

DOUGH MIXING

The amount of bread required on a daily basis to feed astronaut crews should justify automated units. Given the length of the breadmaking cycle and the number of loaves to be produced, it would appear that this equipment will have a sufficiently high level of use that a separate dough mixing/baking system will be necessary to enable the production of other foods such as snacks, english muffins, bagels, rolls, and croissants.

Of the commercially available systems investigated for production of dough for baked goods, the most versatile appears to be the combination of the Cuisinart food processor and the K-Tec mixer. The value of the Cuisinart lies in its unique, gravity-independent capability of very rapidly mixing flour and water to produce a doughball. The K-Tec unit's forte is to knead dough in such a way as to "maximize" gluten development. To accomplish this goal, the K-Tec has the normal mixing cycle options, but once mixing is complete, it offers a special kneading cycle in which sensors monitor gluten development at a given impeller RPM. The cycle is automatically terminated at a predetermined level of gluten development. Doughs made in this way appear more consistent in texture, rise, and bubble size.

The principal difficulty posed by either of these units with regard to CELSS operation is in the area of cleanup. Because of the tight clearances between the blades and housing, and the cohesiveness of most doughs, this is a minor problem in the case of the Cuisinart. Removing the dough and cleanup is a much more significant task in the case of the K-Tec unit. The task is complicated by the increased stickiness of the dough due to its higher gluten development, the center post in the mixing bowl, and the number and configuration of the various mixer parts.

Figure 76 shows a mixer concept design in which all of the agitator parts are attached to the top, including both the stator and agitators. To facilitate cleanup, the lid along with the stator and agitators would be fabricated of a non-stick polymer. To accomplish gluten development, the agitation would be designed to produce the same general level of shear provided by the K-Tec. It is felt that while this revised configuration would be very helpful in facilitating dough removal and clean-up in CELSS operations, they may also be potentially very attractive to the consumer market. These concepts appear to have strong Phase III potential. Preliminary discussions will be initiated with manufacturers to assess their interest, and will be pursued in greater detail as soon as the necessary patent applications have been filed.

ALTERNATIVE BAKING PROCEDURES FOR USE IN CELSS

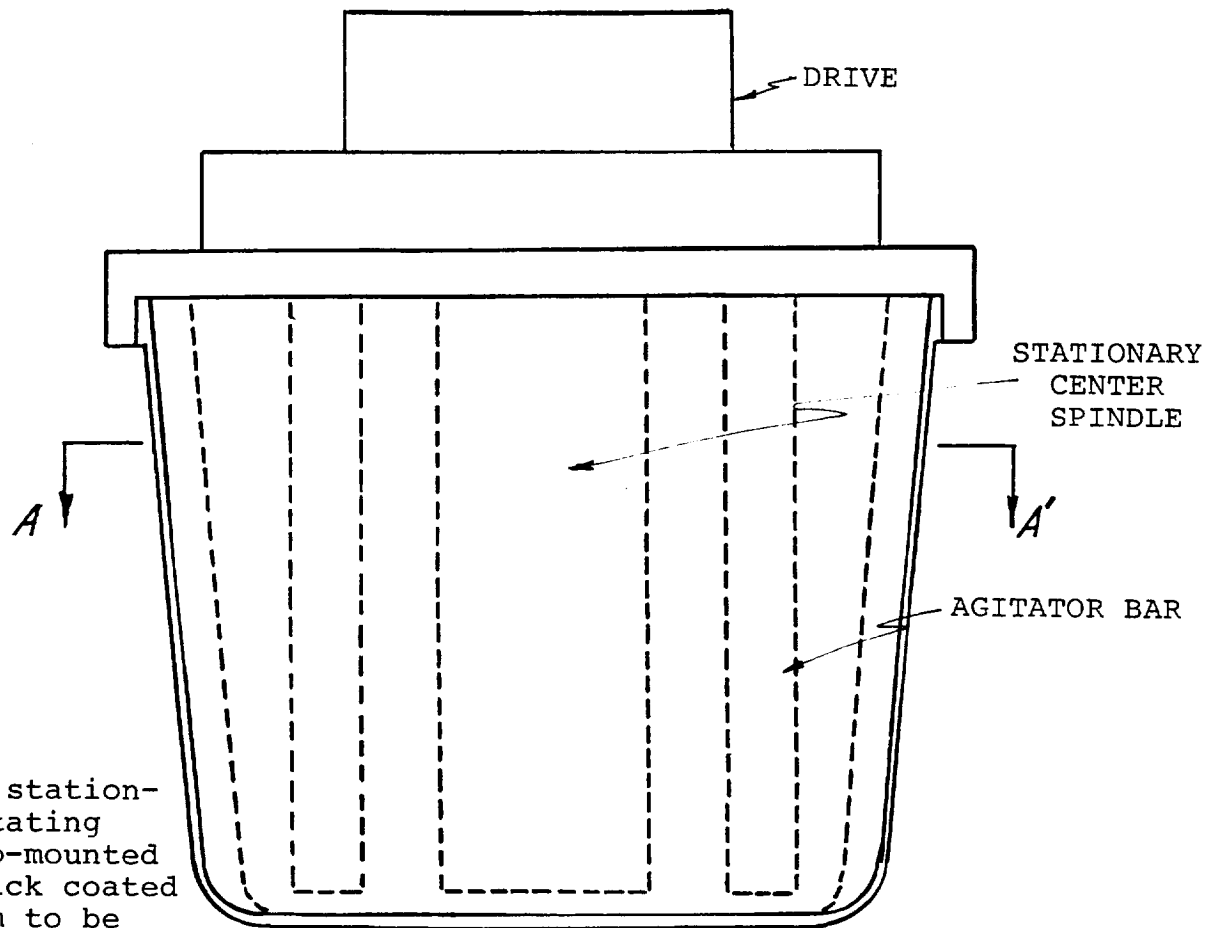
Thusfar two processes have been investigated for production of baked goods. The first involved an integrated breadmaker unit which would incorporate the various mixing, kneading, rising, and baking functions in a single unit. The second involved a four step process using two pieces of equipment, a mixer to combine the flour and water to produce a doughball, a kneader to develop the gluten, a panning step, and the baking operation. The relative advantages/disadvantages of the two approaches are basically as follows:

BREADMAKER

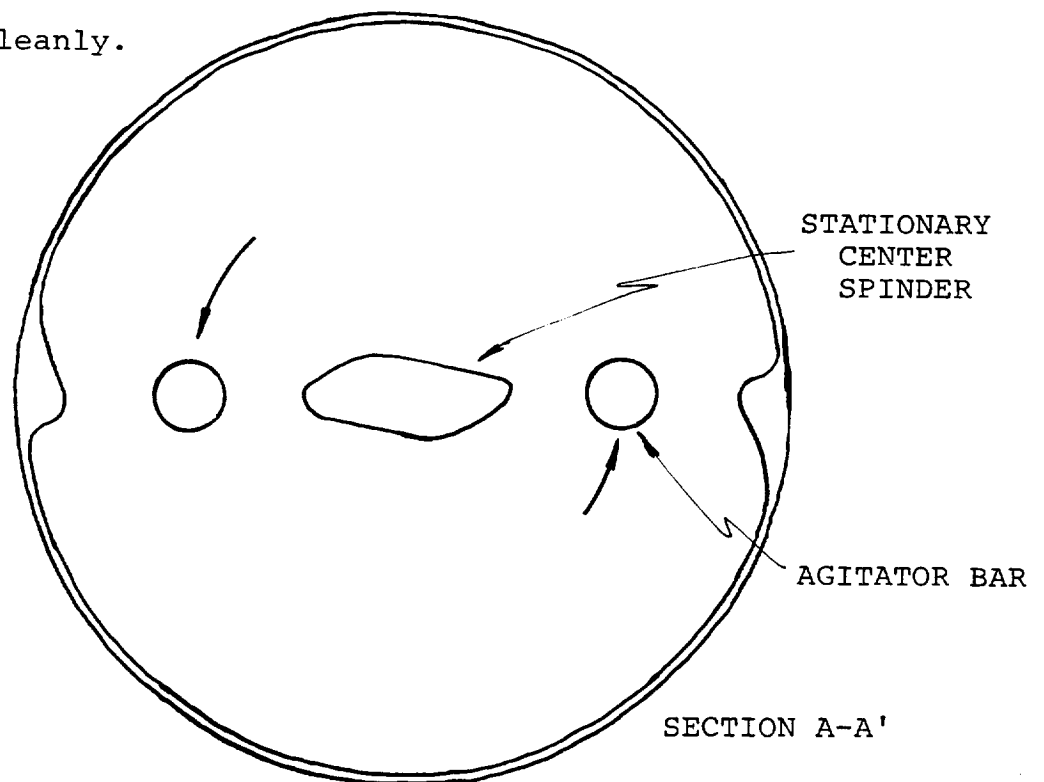
- Advantages: 1.) Except for loading and starting, no human intervention needed to make bread. Other baked goods, such as bagels, english muffins, rolls and sweet rolls would need to be removed at the end of the mixing or kneading process, handled separately.
- Disadvantages: 1.) limited in the types of baked goods it can make.
2.) May not be able to work the dough sufficiently to be able to handle high protein doughs.
3.) May not develop sufficient gluten strength to maintain elasticity in the bread.
4.) Requires approximately 4 hours to produce a loaf.

TWO-STEP PROCESS

- Advantages: 1.) Sufficiently versatile to cope with all baked goods. Ability to handle pasta doughs remains to be tested.
2.) The mixer unit may be useable in a variety of other operations including peeling, slicing, dicing, fry cutting, grating, and dicing. The kneader unit is equipped to handle other doughs, includ-



Having the stationary and rotating members top-mounted and non-stick coated allows them to be withdrawn from the dough easily and cleanly.



DOUGH MIXER

Figure 76

ing pasta, high gluten flours, and cookie doughs

3.) Requires approximately 2 hours per batch.

Disadvantages: 1.) Doughball must be transferred from the mixer to the kneader unit.
2.) In breadmaking, the dough would have to be divided and panned for rising and baking.

A third option has been investigated, in which the mixer is also used to accomplish the kneading operation. The advantage of this approach is the possible elimination of a piece of equipment. Drawbacks may include potentially reduced gluten development. Since these would be driven by powerpaks, the weight advantage would be small, but in terms of cube, this could potentially save approximately 14L. This approach is not entirely new. Robot Coupe uses this method in their commercial food processors, and Mr. Joseph Ortiz, author of "The Village Baker" describes procedures using a food processor. The basic method used in this trial consisted of mixing flour, salt, yeast, and water in a food processor, then letting the resulting dough develop in a refrigerator for 12 hours. It was then shaped into a baguette, permitted to rise and baked. The quality of the result was excellent, and may, in terms of morale, justify the added human involvement.

PASTA PRODUCTION

There are two principal pasta formulations, those that do not contain eggs and those that do. Eggs tend to improve flavor and texture, are commonly included in fresh pastas, and are mandatory in any product labelled as "Egg" pasta. Most commercial pastas do not contain eggs.

Because of their menu versatility, it would be highly desirable to include pastas. The difference would be that stations relying on growing crops in situ for their food, might use semolina and water only, whereas stations being supplied from Earth bases could use a wider range of formulations, including not only eggs but other components, supplied either as individual ingredients or as stable intermediate products.

From an operational standpoint, this would mean that space crews growing their own food, if they are to include pasta in their menu, might need to have the capability of separating endosperm from the germ and bran components of the wheatberry, as well as milling the endosperm as needed.

The question about separations is important because of the need to minimize equipment. Bran constitutes about 17 to 18% of the wheatberry. It is valuable nutritionally primarily for its fiber contribution, but its protein content is roughly analogous to that of the endosperm. The major objection to incorporating bran is the presence of specks in the final pasta. The rationale behind removing germ may be somewhat stronger. Germ is high in both protein (about 25%) and fat (about 7%). This fat is un-

saturated and oxidizes rapidly to produce rancid off-flavors if not protected. Accordingly, the need to remove germ material may hinge on the length of storage time needed for pasta products in a NASA extended mission situation. If consumed fast enough, incipient rancidity may not be a problem, and it may not be necessary to include germ separating equipment for NASA missions. Because the milling requirements for semolina are much less stringent than for flour, a number of mills appear suitable, however in the interest of minimizing equipment weight and cube, it would be desirable to select a mill that has the capability of handling both flour and semolina. Based on FASI's preliminary observation of K-Tec's particle size control, it appears that this unit is very suitable for both operations. Microscopic examination of both semolina and hard red winter wheatberries milled by a K-Tec mill on a "coarse" setting showed the K-Tec endosperm particles to have approximately the same size spectrum as commercially milled semolina. The bran particles were considerably larger and could possibly be screened out to some degree if that would be necessary.

As discussed in prior reports, FASI has recommended extrusion for pasta making over the common roller/sheeter units used for flat pasta. Roller units work well, but the successive rolling operations needed to achieve the prescribed thicknesses make these units excessively labor intensive, and the degree of flouring necessary to prevent sticking could pose a significant hazard in terms of particulate contamination of cabin air and a challenge to maintaining effective particle control.

Recently completed trials using semolina have investigated the requirements of the extrusion process and how it might be improved. Typical commercial formulations would mix semolina and water to produce a dough with a water content of approximately 31 percent. The semolina and water would be metered into a mixer in the proper proportions, pass through one or more conditioning steps, and then into an extruder barrel which would, through heat and kneading create a strong plastic dough which would be forced through the forming die.

For a space crew of 12, the size of extruder would probably be only slightly larger than the small household units such as the KitchenAid and K-Tec. These units do not have the conditioning capability of the commercial units. Typically, the semolina and water would be mixed and kneaded. Thirty-one percent moisture is too low to enable formation of a true dough. With thorough mixing and kneading, however, a fairly uniform batch can be achieved in the form of pellets having a wide range of sizes. These are fed into the throat of the extruder. Lacking ability to do the conditioning and kneading provided by commercial pasta machines, the small household units and larger, intermediate units capable of producing on the order of 14 Kg pasta per hour, aim at achieving the same overall results by slippage and frictional heat, with varying degrees of success. Incorporating egg and other additives can help compensate to some degree, however, many of these options may not be open to a CELSS.

INGREDIENTS

Preliminary trials using semolina on a small laboratory scale unit seemed to indicate 31% moisture may be insufficient given the short residence time for dough formation. Additional moisture (final dough 33%) provided improvement without stickiness.

Insufficient data is available to assess the technical feasibility of milling wheat to make semolina under zero G conditions. As a result, preliminary tests were conducted to examine the potential of making pasta directly from whole wheat. As described above, the major difference chemically is the presence of bran and germ, amounting to about 17% and 0.6%, respectively. Tests run at dough moisture levels of 33 and 35% indicated the higher level formed a stronger, more easily worked dough which extruded more smoothly and resulted in less waste material, but showed little to no difference in stickiness. It would be desirable to examine the effect of even higher moistures on extrusion performance of whole wheat doughs.

Very preliminary sensory evaluation of these materials indicated that while the whole wheat pasta is tan instead of white; and may be slightly "pastier" in flavor and slightly more "tender", the overall product seems acceptable. The addition of a small amount of wheat gluten and/or soy flour, may be beneficial. Product development work would be highly desirable to explore improved formulations and extrusion techniques.

PROCESSING/PRODUCTION

Most household extruders have a screw diameter approximately 4 to 4.5 cm., with a working length of about 5 to 7 cm, and a die diameter of 2.5 to 3.5 cm. These units are not usually intended for stiff doughs or protracted runs, and will stall or even burn out if pushed excessively. With a stiff commercial dough approximately 33 to 35% moisture, production rate is estimated to be potentially on the order of 2.5 Kg/Hr or less. By comparison, a small scale commercial unit, such as might be used by a delicatessen to make fresh pasta, could have a screw diameter of about 5 to 6 cm., with a pitch of about 0.5, and a total screw length of approximately 25 cm, about half of which is in the throat. Two examples are the La Parmesiana and La Venetzia models, which have about 9 and 14 Kg/hr capacity respectively. La Parmesiana dies are about 7.5 cm diameter.

In the laboratory scale trials, the 300 watt KitchenAid unit over-heated and started to smell scorched after about 5 to 10 minutes operation. This was unfortunate because even though the drive may be under-powered for semolina/water pasta doughs, the extrusion head and die plates of the KitchenAid appear well designed. In fairness, it should be pointed out that few of the small scale home pasta unit appeared engineered to handle the stiffer commercial mixes. Most were designed to cope with fresh egg pasta formulations only.

K-Tec was the exception, and performed well. The K-Tec unit is rated for 1400 watts, and has a versatile and well engineered

drive. In K-Tec's pasta making attachment, the extrusion barrel and screw are both made of plastic, and well designed. Laboratory scale tests showed the K-Tec capable of extruding even stiff commercial-type doughs made from semolina with about 33% water.

Test runs with whole wheat flour resulted in adequate extrusion, however, more research will be needed to explore improved formulations to provide better texture and flavor.

Based on our examination of intermediate and household-scale pasta extruders, it would appear that certain comments can be made as follows:

1. The throat and screw should be made of plastic or bronze, not aluminum.
2. A screw of approximately 4.5 to 5.0 cm diameter, with a pitch of about 0.5 would appear very adequate.
3. Commercial and intermediate die plates are historically made of brass or bronze. Given the satisfactory production performance of these materials, NASA could use them or plastic equally well. Because of softness, however, it might be desirable to have additional spares in the case of the plastics. Aluminum should be avoided because of the product discoloration it can cause.
4. The effective screw length for extrusion should probably be on the order of 11 to 12.5 cm.
5. The drive for pasta extrusion should probably be approximately 1.5 HP, well protected against overload and mechanical failure. The K-Tec power unit appeared very suitable from the standpoint of power and engineering.

During Phase II, a number of experiments were conducted using a standard extruder barrel, but with an orifice plate instead of the normal die. The objective of these tests was to assess if this approach could result in quicker and more efficient dough development. Observation indicated that considerable dough development resulted from one pass through a 1.4 cm orifice. Additional passes through a plate having 4 orifices each about 3 mm diameter resulted in significant further dough development. When the orifice plates were replaced by the desired die, the extrusion progressed faster and more smoothly, and the load on the drive seemed considerably reduced.

Figure 77 shows a concept design for an extruder based on the above experiments, which provides an adjustable orifice on a by-pass to facilitate dough development. When the dough reaches an acceptable level of development, the by-pass is closed to direct the flow of dough through the extrusion die.

PIZZA PRESSING

Because of its general popularity, it is desirable to include pizza in astronaut menus. Prior laboratory trials have demonstrated the ability of mixing flour and water to create a suitable dough; coating a formed shell with soft tofu, soy-based

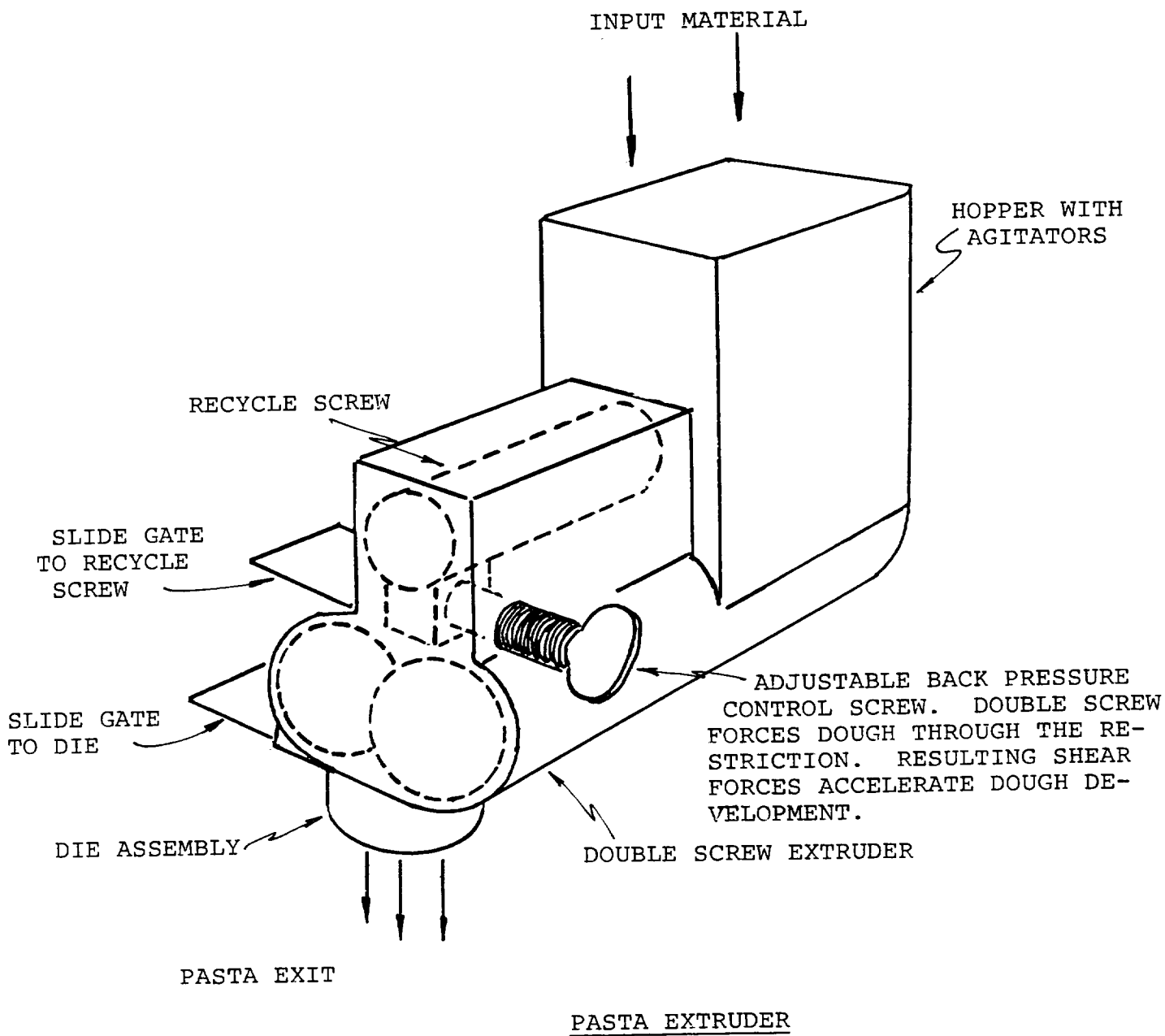


Figure 77

frankfurter slices, bean sprouts and grated soy-based cheeses; and baking the finished pizza in a high air velocity oven. The step in the process which remained to be investigated was forming the dough into the familiar flat, round shell ready for coating.

Monthly reports have discussed the problems posed by sheeter-type units in terms of personnel requirement and particle control due to the flouring needed to prevent sticking.

A procedure suggested as more appropriate to CELSS and zero-gravity was pressing, which involves placing a kneaded, doughball between warmed, non-stick coated plates, and then pressing the plates together to produce a round, flat disc ready for coating. To test this concept, a standard pizza dough formulation/preparation procedure was followed on a reduced scale.

The recipe used was as follows:

Bread baking flour	907.0	gms
Salt	13.6	"
Sugar	13.6	"
Yeast	13.6	"
Oil	22.7	"
Water	.475	L

The batching procedure called for mixing the water, yeast and oil and then adding the rest of the ingredients. These were then mixed at slow speed for 10 minutes. The dough was then divided into 450 gm portions which were kneaded lightly, rounded into balls, coated with oil, and allowed to rise slowly in the refrigerator for 12 to 14 hours. Prior to use, the balls were allowed to return to room temperature. During the mixing and dividing steps it had been noted that the dough was extremely soft and sticky. Refrigerated storage did not stiffen the dough measurably. Some additional flour had been added during the kneading operation, however, this was not sufficient to correct the problem. It is estimated that either the water should be reduced to about .400 L, or the flour increased to 1100 to 1200 gms.

The doughballs were then placed, one at a time, in the press unit which consisted of two Teflon-coated, circular metal plates which could be heated as necessary to facilitate flow of the dough. The lower plate was stationary. The upper plate was manually raised and lowered by a ratchet mechanism to a predetermined gap. During these tests, the doughballs were pressed as desired to create thin pizza shells ready for coating. Because of the excessive softness of the dough prepared for the tests, sticking posed a problem, however, this could be corrected easily by increasing the proportion of flour in the formulation as described above, or by repeating the oil coating applied to the dough. Based on the observed results of this trial, the pizza press device could perform effectively in a CELSS under zero and micro-gravity conditions.

A second device was also tested in which the doughball was not only pressed, but was partially precooked to produce a pizza blank with a raised edge about 1 cm high. These devices are com

mercially available in a range of sizes from individual pizzas to blanks adequate for two or three. The benefit of this approach is the ease of handling, and the advantage provided by the raised edge in retaining pizza toppings during baking in high air velocity ovens such as the American Harvest Jetstream unit.

SOYFOODS

Soybeans have long been prized as a valuable protein and oil source by the food processing industry. Because of their high yield and nutrient density, soybeans offer exceptional efficiency to both producers (growers) and processors. Modern soybean processing plants combine both traditional and high technology methods to give us a wide variety of functional and nutritive food products and ingredients from the soybean including: soybean oil and oil products, soybean meal, flours, fiber products, protein concentrates and isolates, fermented products and meat and dairy substitutes. Table 7 provides information on the composition and nutritional content of some of these products.

Although soybeans vary widely in composition depending on the variety and the region in which they were grown, dried soybeans contain on average:

Moisture	8.5 %
Protein	38.5 "
Fat	17.9 "
Carbohydrate	30.2 "
Fiber(crude)	5.0 "
Dietary Fiber(insol.)	12.5 "
Soluble Carbohydrate	12.7 "
Ash	4.9 "

Based nutritional balance, appropriate production scales, existing technology, and availability of suitable equipment, the following primary soyfoods should be considered for production in CELSS:

- Soymilk
- Tofu
- Tempeh
- Partially defatted soybean meal/flour
- Expeller-pressed soybean oil
- Whole fat soy flour
- Edamame (fresh green soybeans)
- Soy sprouts
- Okara

These primary soyfoods can be further processed into a broad range of secondary soyfoods and food ingredients as follows:

- Milk-like beverages
- Yogurts, Puddings
- Spoonable snacks (dips and spreads)
- Cheese alternatives
- Concentrated soymilk

SOYFOODS — Composition and Nutrient Content

Proximate Composition and Selected Nutrient Content of Various Soyfoods in 100 g. Edible Portions*

SOYFOOD	Water g	Kcal	Protein (N X 5.71) g	Fat g	Carbo- hydrate g	Crude Fiber g	Calcium mg	Iron mg	Zinc mg	Thiamin mg	Riboflavin mg	Niacin mg	Vitamin B6 mg	Folicin mcg
MISO	41.5	206	11.8	6.1	28.0	2.5	66	2.74	3.32	0.10	0.25	0.86	0.22	33.0
NATTO	55.0	212	17.7	11.0	14.4	1.6	217	8.60	3.03	0.16	0.19	0.00	n/a	n/a
OKARA, fiber by-product of soymilk/tolu	81.6	77	3.2	1.7	12.5	4.1	80	1.30	n/a	0.02	0.02	0.10	n/a	n/a
SOY FLOUR, Defatted	7.3	329	47.0	1.2	38.4	4.3	241	9.24	2.46	0.70	0.25	2.61	0.57	305.4
SOY FLOUR, Full-fat, raw	5.2	436	34.5	20.6	35.2	4.7	206	6.37	3.92	0.58	1.16	4.32	0.46	345.0
SOY FLOUR, Full-fat, roasted	3.8	441	34.8	21.9	33.7	2.2	188	5.82	3.58	0.41	0.94	3.29	0.35	227.4
SOY FLOUR, Low-fat	2.7	326	46.5	6.7	38.0	4.2	188	5.99	1.18	0.38	0.29	2.16	0.52	410.0
SOY MEAL, Defatted, raw	6.9	339	45.0	2.4	40.1	5.8	244	13.70	5.06	0.69	0.25	2.59	0.57	302.6
SOY PROTEIN CONCENTRATE	5.8	332	58.1	0.5	31.2	3.8	363	10.78	4.40	0.32	0.14	0.72	0.13	340.0
SOY PROTEIN ISOLATE	5.0	338	80.7	3.4	7.4	0.3	178	14.50	4.03	0.18	0.10	1.44	n/a	176.0
SOY SAUCE, from HVP	75.7	41	2.4	0.1	7.7	0.0	5	1.49	0.31	0.04	0.11	2.83	0.14	13.0
SOY SAUCE, from soy (taman)	66.0	60	10.5	0.1	5.6	0.0	20	2.38	0.43	0.06	0.15	3.95	0.20	18.2
SOY SAUCE, from soy and wheat (shoyu)	71.1	53	5.2	0.1	8.5	0.0	17	2.02	0.37	0.05	0.13	3.36	0.17	15.5
SOYBEANS, Cooked, boiled	62.6	173	16.6	9.0	9.9	2.0	102	5.14	1.15	0.16	0.29	0.40	0.23	53.8
SOYBEANS, Dry-roasted	0.8	450	39.6	21.6	32.7	5.4	270	3.95	4.77	0.43	0.76	1.06	0.23	204.6
SOYBEANS, Raw	8.5	416	36.5	19.9	30.2	5.0	277	15.70	4.89	0.87	0.87	1.62	0.38	375.1
SOYBEANS, Roasted	2.0	474	35.2	25.4	33.6	4.6	138	3.90	3.14	0.10	0.15	1.41	0.21	211.0
SOYMILK, Fluid	93.3	33	2.8	1.9	1.8	1.1	4	0.58	0.23	0.16	0.07	0.15	0.04	1.5
TEMPEH	55.0	199	19.0	7.7	17.0	3.0	93	2.26	1.81	0.13	0.11	4.63	0.30	52.0
TOFU, Raw, firm	69.8	145	15.8	8.7	4.3	0.2	205	10.47	1.57	0.16	0.10	0.38	0.09	29.3
TOFU, Raw, regular	84.6	76	8.1	4.8	1.9	0.1	105	5.36	0.80	0.08	0.05	0.20	0.05	15.0

*Source: Composition of Foods: Legume and Legume Products. United States Department of Agriculture, Human Nutrition Information Service, Agriculture Handbook Number 8-16. Revised December 1986.
Please note that the proximate composition of soyfoods shown here may differ significantly from accepted industry standards.
n/a = data not listed or available

Table 7

Frozen desserts (ice cream substitutes)
Fresh green vegetable (immature pods, sprouts, immature beans)
Salad ingredients (immature pods, sprouts, immature beans)
Textured soy flour
Tempeh-based "meat" replacements (hamburger, meatloaf, etc.)
Tofu-based "meat" replacements (cutlets, stir-fry, etc.)
Snack foods (chips, puffs, crackers, tofu jerky, etc.)
Cooking and salad oil
Salad dressings
Mayonnaise substitute
Margarine-like spread
High fiber flour

Figure 78 shows these and other products that can be made from primary soyfoods.

PROCESSING

Both primary and secondary soyfoods can be processed using readily available processing technology, most of which can use small scale or laboratory-scale equipment. Typical equipment might include the following:

- High speed and/or high shear mixers (Cuisinart, etc.)
- Ovens (with low temperature control for fermentation)
- Extruders
- Dough mixers
- Ultra-filtration systems
- Steam jacketed cookers
- Grinders (both coarse and fine)
- Coolers
- Ice cream freezer

Description of the various primary and secondary processes are as follows:

PRIMARY SOYFOODS PROCESSING

Individual flow charts are provided for most of these processes (where noted)

SOYMILK

Soymilk is the aqueous extraction of whole soybeans and is the base ingredient used to produce not only a milk-substitute beverage, but is also used to make tofu, soymilk yogurt, soymilk-based cheese alternatives, frozen desserts and other spoonable foods and snacks.

Figure 79 shows four methods of producing soymilk: the traditional Oriental method, one devised at Cornell University, one developed at the University of Illinois, and the ProSoya method. What follows are detailed descriptions of the various steps involved in these processes.

MODERN SOYFOODS

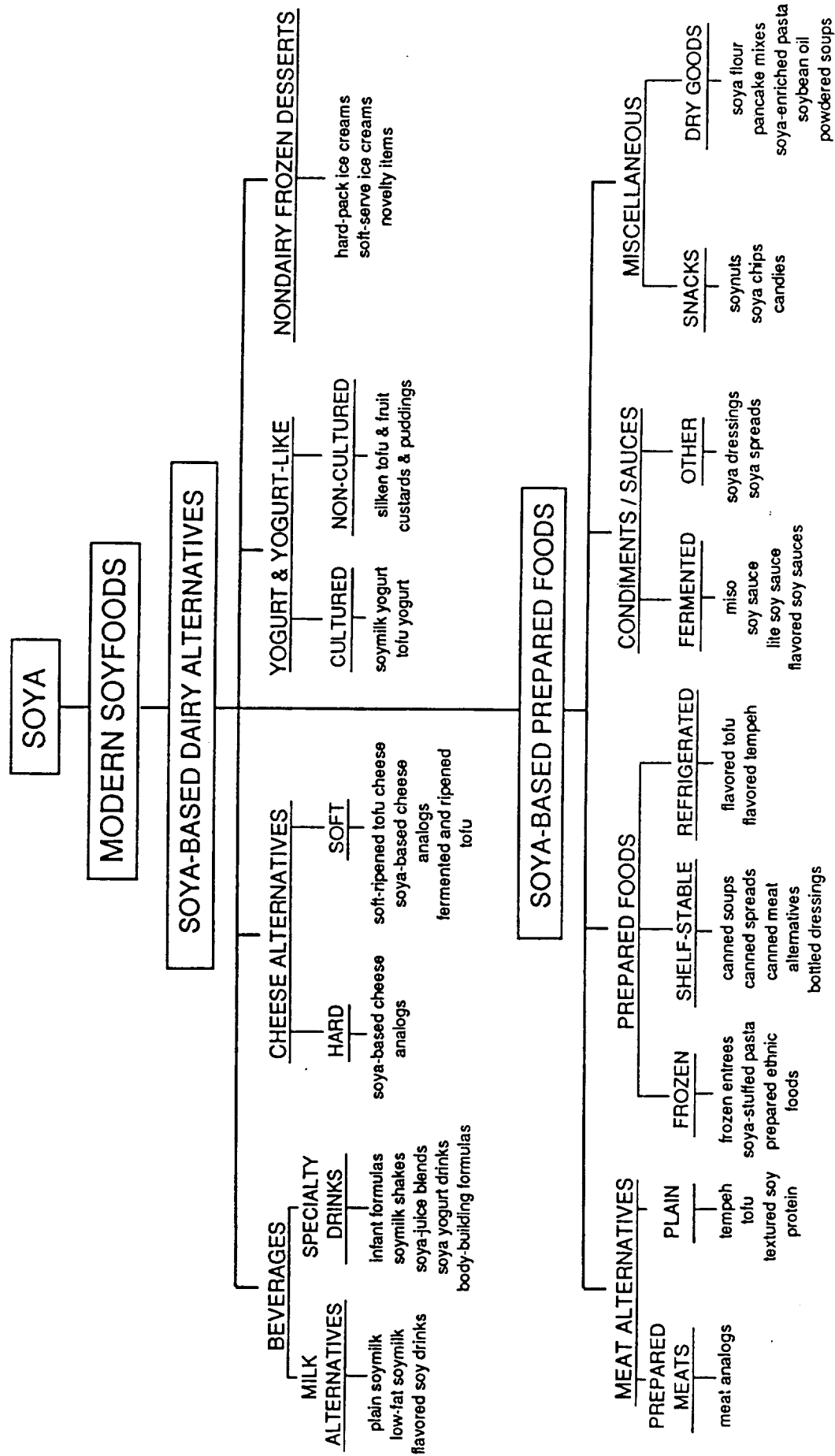


Figure 78

METHODS OF SOYMILK PRODUCTION

PROCESS	TRADITIONAL	CORNELL	ILLINOIS	PROSOYA
	<p>SOYBEANS ↓ SOAK OVERNIGHT ↓ COLD GRIND ↓ ↓ COOK (100°C 20 MIN) FILTER ↓ ↓ FILTER COOK (100°C 20 MIN)</p>	<p>SOYBEANS ↓ SOAK OVERNIGHT ↓ HOT GRIND ↓ COOK (100°C 10 MIN) ↓ FILTER</p>	<p>SOYBEANS ↓ ALKALINE SOAK ↓ BLANCH (100°C 10-20 MIN) ↓ GRIND ↓ COOK TO 82°C ↓ HOMOGENIZE</p>	<p>SOYBEANS ↓ SOAK OVERNIGHT ↓ COLD GRIND IN WATER WITHOUT OXYGEN ↓ COOK (100°C 10-20 MIN) ↓ FILTER</p>
BEANY FLAVOR	STRONG	IMPROVED	NONE	NONE
SOLIDS YIELD	61% (55-65%)	65%	89%	75%
PROTEIN YIELD	73% (70-80%)	83%	95%	80%

Figure 79

SOAKING

Soybeans are typically soaked at ambient temperature for 8 to 12 hours before processing. This soaking helps to reduce the energy required for grinding the beans and begins the solubilizing of the soybean fractions. Soaking time can be reduced dramatically by using water at higher temperatures. For example, depending on the type, size and residual moisture level of the soybean, the soaking time can be reduced to 4 to 6 hours at 38C, or to as little as 1 to 2 hours at boiling. Soybeans are usually soaked in about 3 times their weight of water. After soaking, the soybeans should weigh about 2.2 times their original weight.

Before soaking, the soybeans are usually rinsed and drained to allow for the removal of dirt and to reduce the bacteria count of the finished products. Some of the disadvantages to soaking are the need for excess water since non-absorbed water is later drained off; the extra space required for soaking tanks; the loss of some protein in the water; the beginning of the formation of off-flavors from the reaction of the lipoxygenase and water; the extra time necessary to prepare for processing; and the fact that if one needs to stop the downstream processing at any time, the soaked soybeans are not stable and cannot be kept long.

Alternatives to soaking prior to processing are: grinding dry soybeans with water, as is done with Alfa-Laval's soymilk processing system; pre-flaking, as with the Nichii MicroSoy flakes; or using a freshly ground, fine (100 mesh or finer) whole soybean flour. In the Alfa-Laval system, dry whole soybeans are ground in a two-stage grinder in the presence of boiling water and sodium bicarbonate. With the Nichii flakes, dry flaked soybeans are simply slurried into the water and cooked as normal.

Another possible method which needs further investigation is the pre-cooking of dry (unsoaked), cracked soybeans with an extruder at controlled temperatures (to be determined, but probably in the range of 71C to 93C) prior to slurrying with water. This method, although not practiced commercially, may permit the use of unsoaked soybeans to make soymilk with a bland flavor.

Obvious advantages to not soaking the soybeans prior to processing are the space and water saving attributes, as well as possible improvements in flavor resulting from limiting the lipoxygenase and water reaction.

GRINDING

All of the different approaches to grinding discussed below yield a soybean slurry requiring additional heat treatment for proper processing. Typically, the amount of water that has been added to soybeans to make a slurry before cooking (including that absorbed in the soaking stage) is between 8:1 and 10:1.

Traditional processes used in the Orient have relied upon using the simple stone grinding of soaked soybeans with cold water. While this produces a soymilk with the naturally occurring "beany" flavor which is acceptable in China, this product would

be unacceptable to most Western palates.

A simple improvement to this "traditional" process can be made by using what is referred to as a "hot water grind". This method, discovered by researchers at Cornell University, uses boiling or near boiling water in the grinding stage (water and soybean slurry should not drop below 85C). This necessitates the use of a stainless steel grinder, as opposed to stone grinders. The boiling water inhibits the reaction of the lipoxygenase enzyme on the lipids in the soymilk, thus reducing or eliminating the beany flavor that this reaction creates. There is also an increase in both solids and protein levels, as well as an improvement in mouthfeel.

Researchers at the University of Illinois developed a method which introduced the concept of using an alkaline soak to reduce the oligosaccharides in the soybean and to help inhibit the reaction of the lipoxygenase enzyme. It also utilizes the whole soybean by using a two stage grinder and homogenization to incorporate all of the fiber into the soymilk instead of separating it out later as is done with most other methods. Although this produces a relatively bland soymilk with all of the soybean's fiber and the highest solids and protein yield of any method, this soymilk tends to be slightly chalky and leaves a drying sensation on the back of the mouth. Also, because of the high fiber content, soymilk produced this way would be not suitable for further processing with ultrafiltration.

A relatively new patented process developed by ProSoya Foods International in Canada is based on the premise that it isn't only the water that helps to activate the enzymatic reaction that creates the beany flavor in soymilk, but it is the presence of oxygen as well. Elimination of oxygen in the grinding stage results in elimination or reduction of the beany flavor. ProSoya's processing unit is a single chamber grinder/pressure cooker in which the soybeans and water are placed. The chamber filled with water, so that no air remains. When the grinding occurs, there is no oxygen available in the chamber to mix with the soybeans and water. This allows the use of cold water in the grinding stage, thus decreasing the chances of denaturing the protein. The soymilk is cooked inside the grinder/pressure cooker unit after grinding.

Recommendations:

Because of the obvious problems related to soaking soybeans in water in a zero gravity environment prior to processing; and in addition, the extra space, water and time required, it would be best to use a system which can use dry unsoaked soybeans, either whole or ground, for processing. This would require choosing between:

- A pre-flaking system as with the Nichii flakes;
- A two-stage, dry soybean and water grinding system (as with the Alfa-Laval type system)
- A flour mill capable of fine grinding a whole soybean prior to slurring with water;
- A modified ProSoya processing unit, capable of grinding dry

whole or cracked soybeans or flour; or
An extruder which can process cracked soybeans at a controlled temperature.

COOKING (Heat Treatment)

Adequate heat treatment is required to properly inactivate the trypsin inhibitors (TI) inherent in the soybeans and to allow for proper solubilizing of the protein, oil and carbohydrate fractions of the soybean.

Heat treatment or cooking can be easily accomplished within a pressure cooker. If heated at 99C, cooking times of 7 to 20 minutes are required to inactivate the TI and to achieve a high solids yield. Higher temperatures allow for a shorter cooking time.

Another method of cooking is with steam infusion in a tubular heating system, as is used in many modern large-scale, continuous processing operations. Because of the high temperatures which can be achieved with these systems, cooking time can be reduced to just a few minutes. For example, at 143C (289F), the soy slurry need only be heated for 30 to 60 seconds to achieve TI inactivation and maximum solids recovery. For more time and temperature information, see the table in "steam infusion cooking of soymilk" in appendix.

The ProSoya system, with its single unit grinder/cooker, can cook the soybean slurry under pressure in the same closed vessel that it grinds in. Full cooking can be accomplished in 10 to 15 minutes.

If finely ground whole soybeans (whole fat soy flour) are used, and this flour is added to boiling or near boiling water, the small particle size of the flour allows for adequate heat treatment in just a few seconds or minutes, depending on the temperature of the water or steam.

If extrusion cooking of the dry soybean can be used, because of the rapid temperature rise in the extruder and the pressure under which the extruder operates, it is conceivable that little or no additional heat treatment needs to be applied to the meal once it exits the extruder and is mixed with near boiling water. The temperatures achieved in the extruder will inactivate most if not all of the TI in the soybean.

RECOMMENDATION:

The use of whole fat soy flour merits further investigation as it will not only allow elimination of soaking the soybeans prior to processing, but it will also reduce the time required for adequate heat treatment. If it is desired to retain the fiber in the final soymilk, a finely ground soy flour should be used. If it is intended to remove the fiber, as is discussed below, it would be desirable to use a more coarsely ground flour to result in a higher solids yield after fiber removal.

Further research should be conducted on the viability of using extrusion cooking of the soybeans as it not only allows eliminating soaking the soybeans, but should also drastically reduce, if not eliminate, the additional cooking time required (to inactivate TI) prior to further processing.

FIBER REMOVAL (Okara Extraction)

After adequate cooking of the soybean slurry to inactivate the soybean's antinutritional factors, it is necessary to remove the soybean pulp, or okara (Japanese term) from the soybean and water slurry. This separation produces a milk-like base with around 8.5% solids and a soybean-fiber pulp mass typically containing 70-75% moisture. We are assuming that this okara will be dried or held aside for further processing into bread mixes, snacks, burger mixes, or can be used as a base ingredient in an extruded snack food. If dried, the okara can be milled into a high-fiber flour.

Traditional batch processing of soymilk utilizes a simple hydraulic press to remove the okara. To do this, the soymilk is first poured through a coarse-weave nylon bag and allowed to flow out until most of the readily available liquid has been drained off. This bag is then arranged in the center of the pressure plate at the bottom of the chamber and tied closed. The reinforced lid is lowered and shut. A hydraulic pump pushes the pressure plate and the bag of wet okara up against the lid. The pressure is maintained for 2 to 5 minutes, or until the milk stops flowing. The lid is opened and the bag of hot okara is removed. The hot soymilk usually pours from this unit directly into a waiting tank. Because there are fines that pass through the coarse woven nylon bag, additional filtering of the soymilk is required with a fine mesh nylon cloth or stainless steel screen.

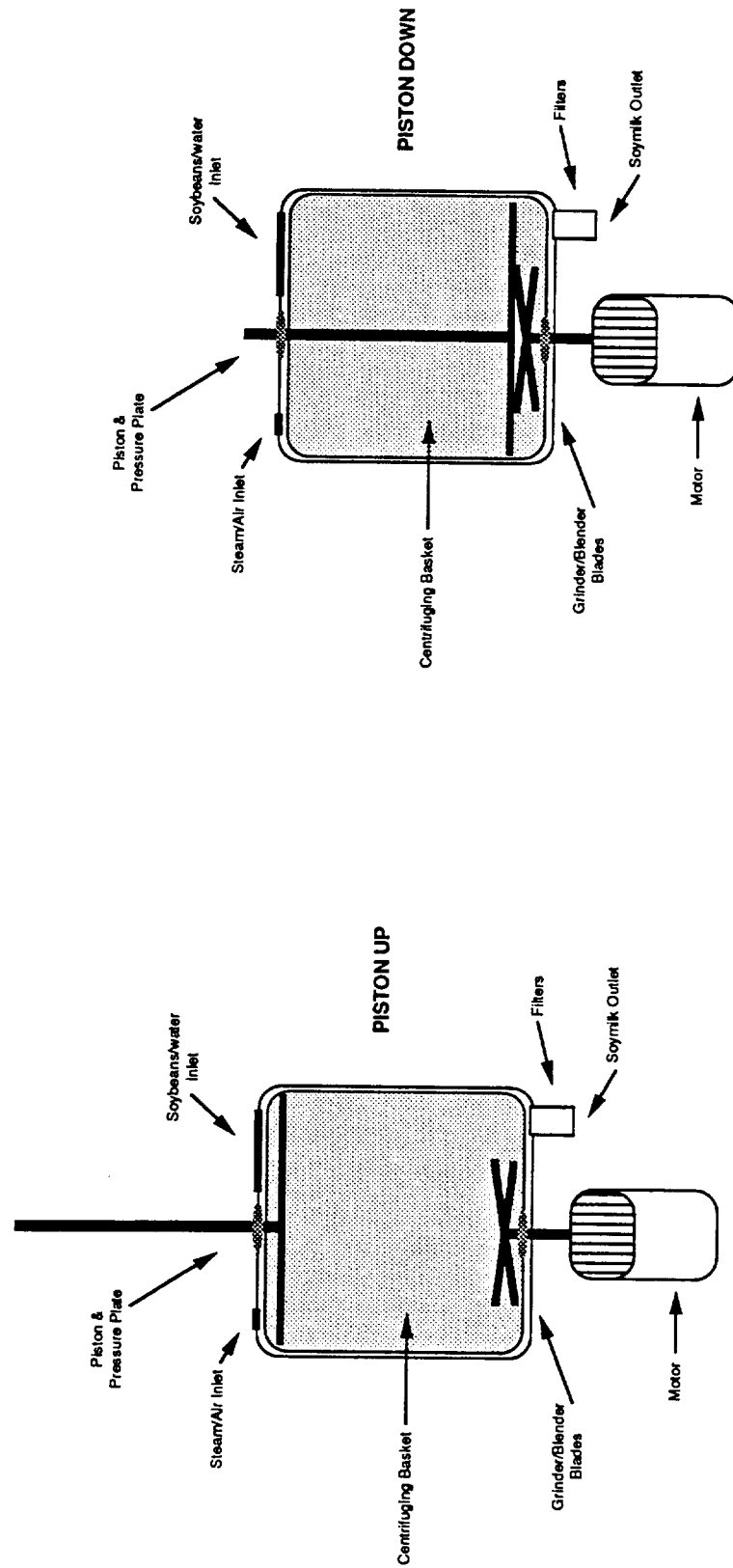
In a large continuous system, a decanting centrifuge is the best piece of equipment to use for this. This essentially moves the slurry down a screened chamber with an auger. As it pushes the slurry against a fine screen, the soymilk passes through the screen and the okara is ejected out of one end.

Neither one of the above mentioned processes are suitable for use in a zero gravity environment as gravity is an integral part of both of these processes.

An option to consider is the use of a centrifuging basket within a vessel (see Figure 80). The soymilk slurry would be pressed from the top, inside of a perforated basket. Soymilk would flow out of the basket and be drawn by vacuum to the exit port. After the initial pressing, the basket would be spun at high speeds to force any remaining soymilk out of the okara and into the chamber, where it would be drawn out.

This centrifugal-basket unit could be part of the single vessel ProSoya processing system. This single vessel system can currently grind and cook the soybeans in one unit. If it was desired to add the okara removal as an additional process, this single unit would grind, cook and remove the fiber. At this

Modified ProSoya System with Pressure Plate and Centrifuging Basket for Okara Removal



Piston is up during grinding and cooking stage of soybeans and water.

After cooking, soymilk is drawn out through outlet on bottom. Piston is lowered to force additional soymilk out. After pressing, the centrifuging basket is activated. The basket is run on the same drive shaft as the grinder blades and is engaged for operation. This forces remaining soymilk out of the okara through the perforated basket and into the outer vessel where it is drawn off.

Figure 80

point in time, the ProSoya system uses only soaked soybeans, which would pose difficulty for CELSS. It is possible that freshly ground soybeans or soy flour could be used in the ProSoya system, instead of soaked soybeans, and this would eliminate the soaking step.

It is also possible to leave the fiber in the soymilk and homogenize the final product at 500 psi for the first stage and 3500 psi for the second stage (or higher). This essentially shatters the cell walls of the fiber and creates a smooth suspension of fiber particles. This soymilk can then be used to make tofu, yogurt or beverages, although as a beverage, some mouth-drying sensations are evident from the fine fiber.

The advantage to leaving the fiber in and processing with homogenization is that we achieve a 100% utilization of the soybean. There is no waste to further process. In addition, the fiber acts as a natural stabilizer when the soymilk is used for further processing, allowing the production of creamier tofu, yogurts and ice creams.

Recommendations:

Okara removal in zero gravity poses many problems, and is not entirely necessary in this situation. As a result, the whole soybean should be used for some, if not all, of the soymilk products. Using the whole soybean would give us a 100% utilization, and result in not having a waste by-product to further process (the okara).

A disadvantage to leaving the fiber in is that we may want to use ultrafiltration downstream to remove some of the carbohydrates and condense the soymilk prior to making tofu or other products. This fiber would clog up any ultrafiltration system.

ULTRAFILTRATION

After the soymilk is processed, the result is a fairly bland, slightly off-white liquid containing from 8 to 10% solids, with approximately 3.6% protein, 2.0% fat, 2.9% carbohydrates and 0.5% ash. At this point in the processing, consideration should be given to using ultrafiltration (UF) to remove some of the water and the soluble carbohydrates. This would bring the solids content of the soymilk up to about 22-24%. By removing the carbohydrates, it would make a soymilk that is easier to digest (when reconstituted into a beverage) and also concentrate the soymilk for further processing into finished products like tofu.

Using UF to concentrate the soymilk before making a soymilk beverage allows us to store the concentrated soymilk in a smaller vessel, saving space. All of the recommended products, tofu, soymilk, yogurt and ice cream, can be made using the UF treated soymilk either as a concentrate, or after having been reconstituted back to an 8-10% solids level.

A small UF system can be designed fairly easily using readily available technologies. A small closed tank would have one or

two small UF cartridges mounted on the outside. The soymilk would be circulated in a loop continuously through the tank and back out through the filters until the desired level of solids was reached. The permeate, or whey, would be drained out of the cartridges. This permeate could be treated again in another system to remove the solubles (through reverse osmosis) and the water could be used once again. The carbohydrates and other solids retrieved could perhaps be used in another food system.

TOFU

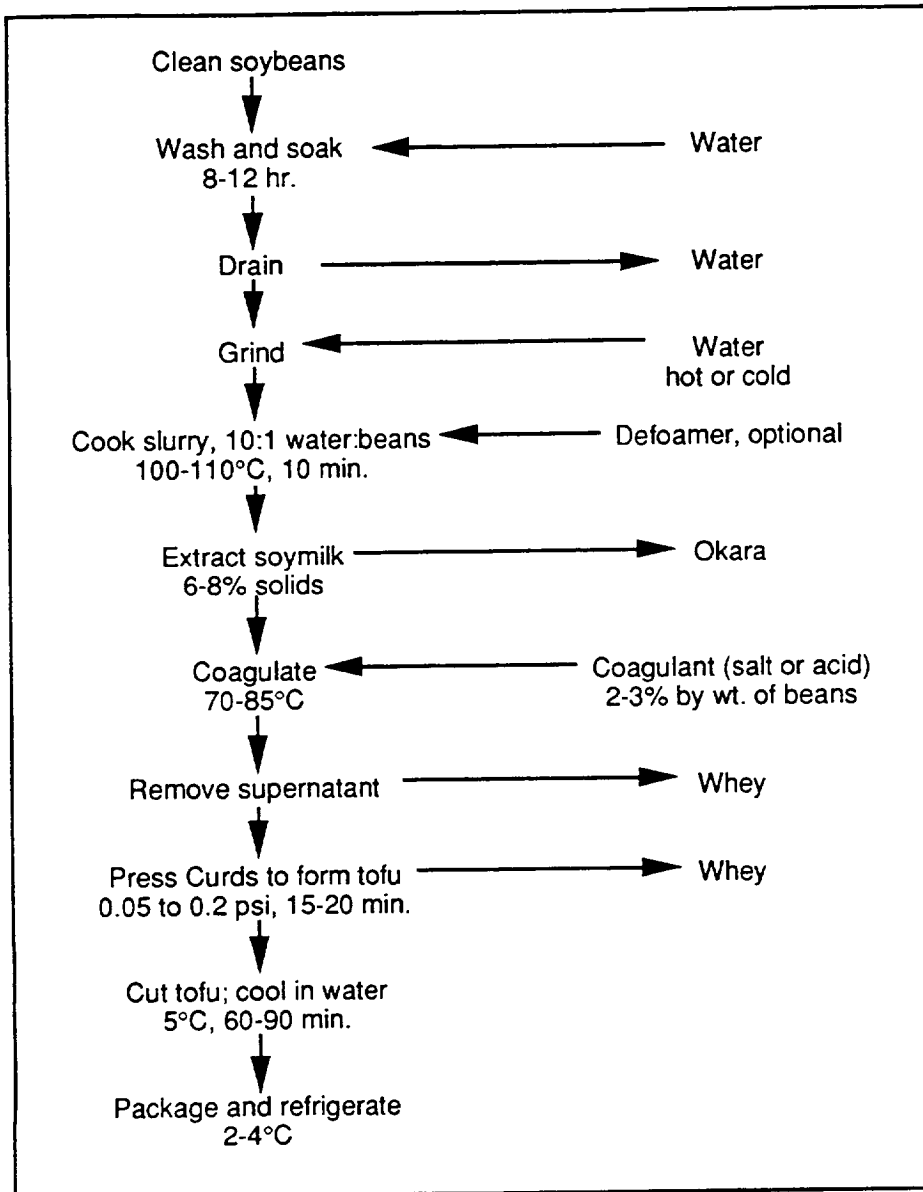
To make tofu in the traditional manner (see Figure 81), hot soymilk (71C-82C) is coagulated with a solution of magnesium chloride or sulfate, or calcium chloride or sulfate (or suitable food grade acids), in an open vessel for a period of 10 to 20 minutes. The amount of coagulant used is usually between 1.5% and 3.0% of the weight of the dry soybeans, added to a small amount of water. During coagulation, white curds form in a vat of yellow whey. Curds and whey are then separated. This process would obviously be impossible to perform this way in a zero gravity environment.

One possible solution would be to coagulate the soymilk in a closed vessel that had another container inside of it with a screen on top and bottom. After the coagulant has been added to the soymilk, pressure could be applied to the top screen and force the whey out of the inner vessel and into the outer vessel, where it would be drawn off with a vacuum. The coagulated curds, under pressure in the inside vessel, would be pressed into a large block of pressed tofu. See accompanying flow chart for more information.

Making tofu with UF treated soymilk would be much easier to do in a zero gravity environment. To make tofu with UF soymilk, one takes the concentrated soymilk at 22-24% solids at 55 to 60C and adds a coagulant such as magnesium chloride, calcium sulfate (or both combined) or glucono-delta-lactone (GDL). The mixture is then placed in a container and heated to at least 80 to 90C for coagulation to occur in the container, or up to 120C in an autoclave for coagulation and sterilization in a can or other suitable container. Since most of what would be whey has been drawn off in the UF process as permeate, little or no wheying off results when making tofu this way. Essentially what is formed is one big tofu curd.

Using UF treated soymilk to make tofu makes the process much easier, but the texture and flavor of the product is not exactly the same as with pressed tofu. The texture of the UF treated soymilk tofu is softer and less cohesive, as no pressure has been applied to the curds to form a complex matrix. Pressed tofu that is made under pressure with regular coagulated soymilk is more versatile for further processing into other meat substitutes as curd size and texture can be varied. Tofu that is made with UF treated soymilk has less variable textures. The big advantage of using UF treated soymilk to make tofu is that the process can be accomplished in a closed system and is easy to control.

Flow Chart for Regular Tofu Production



Source: Shurtleff, W. and Aoyagi, A., Tofu & Soymilk Production, The Book of Tofu, Volume II, 1979. The Soyfoods Center

Figure 81

Tofu can also be further processed by flavoring and baking, frying, freeze drying or dehydrating into meat substitutes or ingredients to be processed into meat substitutes.

TEMPEH

Tempeh is one of the family of fermented soyfoods and is quite unique in its texture, flavor and versatility. When well made, tempeh is a compact cake completely covered with and penetrated by the white mold mycelia of the *Rhizopus oligosporus*. One kilo of dry soybeans will yield almost two kilos of finished tempeh. Tempeh has none of the beany flavor associated with raw soybeans and requires little cooking time.

The availability of an appropriate and clean starter culture is essential for producing a good quality tempeh. Once a good culture has been established, it will need to be maintained in an in-house lab.

To produce tempeh, whole dry soybeans are dehulled by either mechanical means, during which time they may be split and cracked as well, or by soaking and cooking whole dry soybeans for 30 min in boiling water to loosen the hulls (see Figure 82). The hulls can then be removed by hand and washed with water to separate them from the cotyledon. The dehulled soybeans are then soaked in water to which a dilute acid has been added, such as lactic or acetic, for 30 min @ 100C. The pH of the soaking solution should be in the 4.3 - 5.3 range. After soaking, the soybeans are cooked in the boiling soak water for up to 90 min @ 100C. After cooking, the soybeans are drained thoroughly and allow to cool to 38C before inoculation. After drying and cooling, about 3 g of dried, pulverized tempeh culture per 1 kg of cooked, drained soybeans is mixed thoroughly with the soybeans. The inoculated soybeans are then put into plastic bags in which numerous air-holes have been added to allow for limited aeration and relatively high humidity during incubation. The bags of inoculated soybeans are then laid out on trays and incubated at 35-38C and 75-78% relative humidity for 18 to 24 hours. Tempeh should be refrigerated for extended shelf-life, or can be frozen, fried or processed into other meat substitute products such as burgers or tempeh strips. See accompanying flow chart for more information.

Recently, researchers at the Hebrew University of Jerusalem have devised a new, more efficient process for producing tempeh. In this process, non-dehulled, whole flaked soybeans were wetted with slightly acidified water (by either citrus vinegar, lactic acid or citric acid) at a ratio of 1:1.4 (flakes:water). The moist flakes are steamed in a colander placed above boiling water at atmospheric pressure for 0 to 10 minutes. The steamed flakes are then cooled to 37C and inoculated with *Rhizopus oligosporus* spores. The thoroughly mixed, inoculated flakes are then packed in plastic bags and incubated at 31C for about 24 hours until an even, white mycelium covered the flakes and a firm cake has formed.

The resultant tempeh was equal to, if not superior in flavor and texture to traditionally produced tempeh. The major advantages

Flow Chart for Tempeh Production

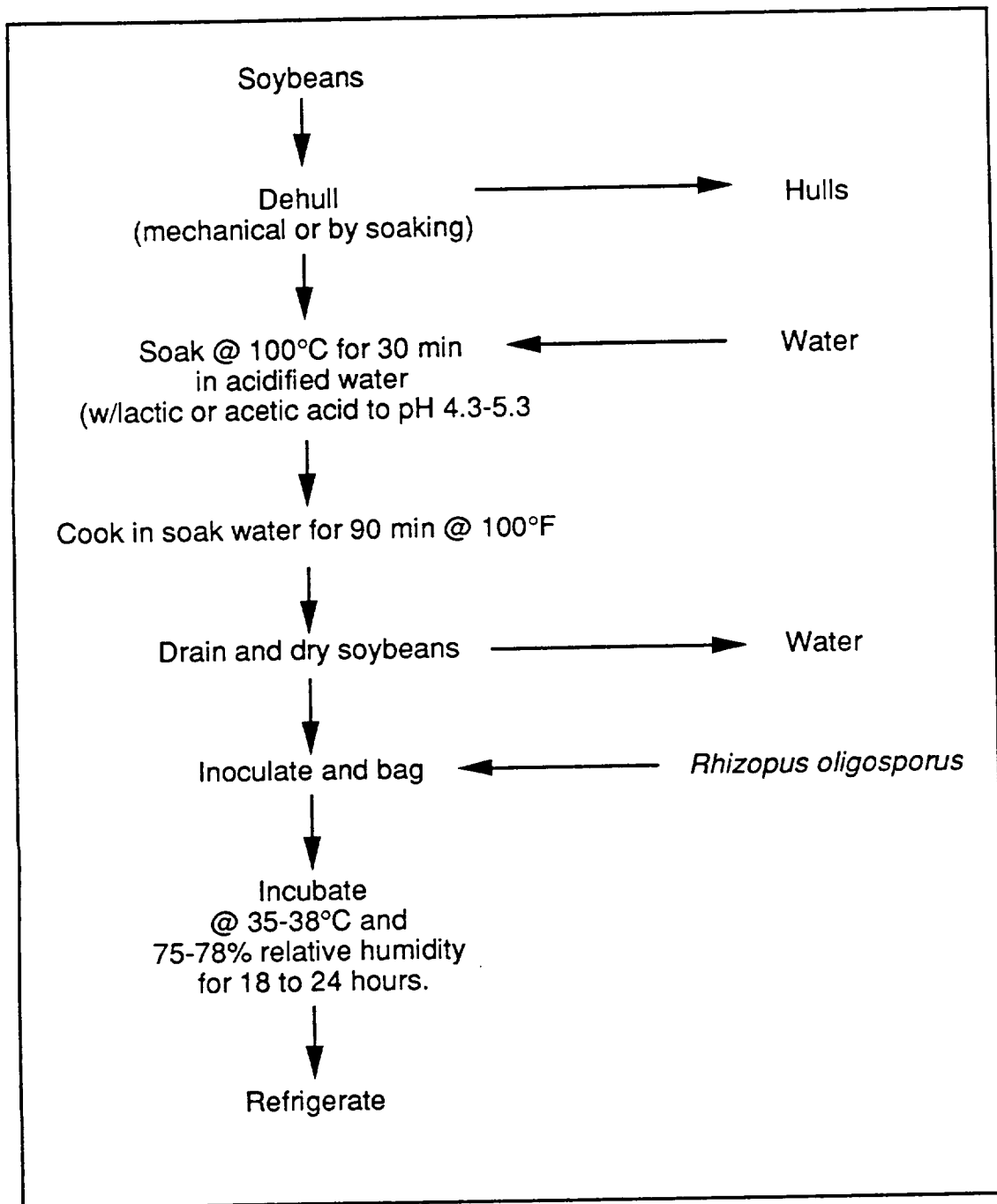


Figure 82

of this process are that no soaking or precooking of the soybean is required, resulting in less energy and water used during processing. This results in a higher yield of finished product and less waste to recycle or dispose of. In addition, because non-dehulled soybeans are used, the fiber content of the finished tempeh is higher than regular tempeh as is the Vitamin B12 content.

A flaking and cracking system is needed for pretreatment of the soybeans and preparation of the flakes for this process. In addition, an investigation will be needed to determine the possibility of using extruded soybeans which could be acidified before inoculating with the *Rhizopus oligosporus* spores.

EDAMAME

Edamame, or immature green soybeans, are a popular fresh vegetable in the Orient. Relatively unknown and certainly underutilized in the United States, edamame can serve as a fresh green vegetable in salads or as a cooked vegetable by itself or in prepared dishes. Green soybeans contain an average of 12% protein on a wet basis and are rich in unsaturated fatty acids, including the omega-3 factor and essential vitamins and minerals.

Depending on the variety, green soybeans can be picked from 60 to 90 days after planting. The soybeans are optimum for picking during a one- to two-week period. Green soybeans can be effectively picked using a combine-type green pea harvester. This type of harvester not only cuts and harvests the beans, but it also depods and cleans the beans. On a small scale, green soybeans may be harvested by hand and frozen in the pods for later processing. If the beans are depodded prior to freezing, they should be cleaned and blanched in boiling water for at least four minutes, then quick frozen at minus 40C. Freezing preservation may not be compatible with CELSS. Green soybeans prepared in this manner can be available for serving in about one minute.

SOY SPROUTS

Dried soybeans can be soaked and germinated to make a small sprout, similar in appearance to the better known mungbean sprouts (bean sprouts). To make soybean sprouts, presoaked soybeans are poured into a container with a drain and are covered to avoid evaporation and exposure to light. The soybeans must be watered frequently to reduce the heat generated during sprouting. It usually takes from 5 to 10 days for the sprout to reach a desired length of about 5 cm (2 in.), depending on the temperatures. Although any soybean can be used for sprouts, smaller varieties are preferred.

A special feature of the soybean sprout is the considerable amount of ascorbic acid (vitamin C) synthesized during sprouting. Usually no ascorbic acid is found in the dried soybean. The oligosaccharides stachyose and raffinose are metabolized during sprouting, and at the same time, the TI activity is decreased and the protein digestibility is increased.

The sprouts can be eaten as a fresh vegetable or added to prepared dishes. They can also be added to bread dough as a sprouted grain to add texture and nutrients.

SOYBEAN PROCESSING BY MECHANICAL EXTRUSION/EXPPELLING MEANS

Recent innovations in soybean oil extraction developed by the International Soybean Program (INTSOY) at the University of Illinois at Urbana can be utilized to a great degree in the processing of soybeans to make protein meal and oil (see Figure 83).

In this processing, an INSTA-PRO tapering screw extruder is used to cook the soybeans. High temperatures and the force of shear and compression within the extruder disrupt the oil-bearing tissues, producing temperatures of 138C for 30 seconds and turning the soybeans into a nearly fluid state. A significant portion of the oil can be recovered when the extruded material is semi-fluid and fed immediately into a mechanical oil press.

The result of combining the extruder and expeller into a single operation is an oil extraction rate from soybeans approaching 75% (4-5% fat remaining in the partially defatted flour) with only a single pass. This soybean oil contains natural antioxidants, therefore requiring little further processing, except for filtering or settling to remove sediments. Because of the antioxidants, the clear, golden oil is highly stable and has little or no off-flavor.

After extraction, the partially defatted soybean meal is conditioned and cooled simply by passing the meal through a rotating, fluted drum which allows the remaining moisture in the product to be vented off. After cooling, the 30-40 mesh soybean meal grits can be ground into a finer flour for incorporation into baked goods, or for further processing into textured soy flour for meat analogs or for storage.

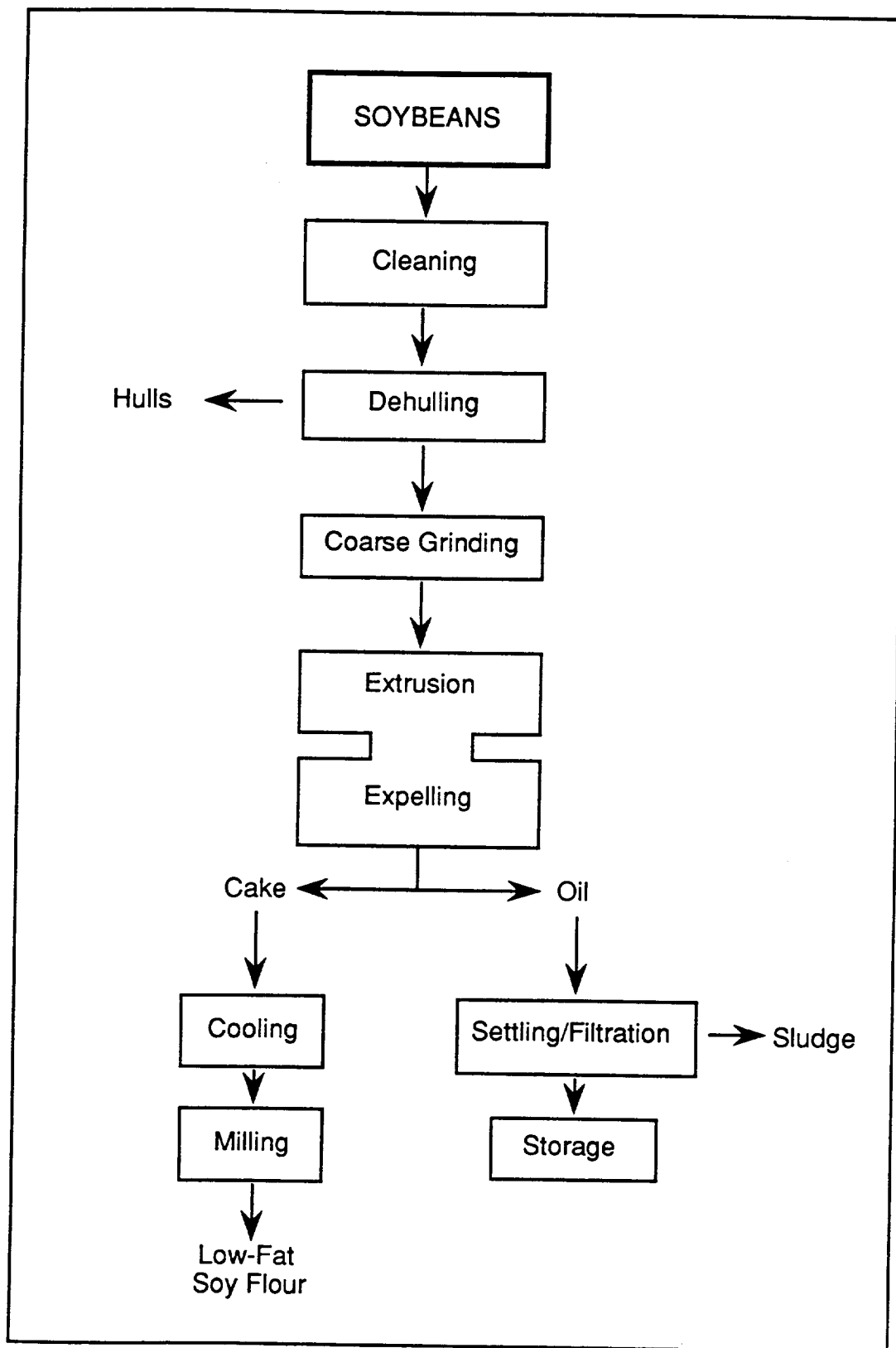
Although the INSTA-PRO extruder is the machine of choice due to its ease of operation and flexibility in processing, and because all of the heat used in the process is generated by friction and compression in this machine, the scale of operation needs to be large enough to generate the necessary heat for processing. As a result, INSTA-PRO's smallest unit at this time is capable of processing 600 pounds per hour. This is estimated to be 3 times the total anticipated monthly need of 200 pounds for a twelve person crew. A much smaller-scale extruder is needed. It is possible that this smaller extruder will need to have a heated jacket, as the volume likely to be processed would be insufficient to generate enough heat on its own for proper processing.

EXPPELLER-PRESSED SOYBEAN OIL

The raw soybean oil obtained through this system will need only slight processing. Filtration by fine screens or other simple means should remove most of the undesirable larger particulates.

Soybean oil is naturally low in saturated fats and high in Omega-3 fatty acids, believed to help maintain low cholesterol levels. In addition, soybean oil processed in this manner contains a high

Soybean Processing By Extrusion / Expelling



Source: INTSOY, University of Illinois at Urbana

Figure 83

level of tocopherols, or Vitamin E, as well as lecithin, all believed to be beneficial to the health. In addition, by retaining the Vitamin E, a natural antioxidant, the soybean oil is very stable and may be stored at ambient temperatures without developing rancidity. The lecithin enhances the oil's ability to be used in frying as well. Because of its stability, this soybean oil could be used in all cooking, frying and baking applications.

PARTIALLY DEFATTED SOYBEAN MEAL/FLOUR

The partially defatted soy flour, containing approximately 49% protein and 4.5% fat, obtained from the milling of the low fat soybean meal will be utilizable in a wide variety of food applications, including bakery goods, pasta products, sauces, snack foods and extruded flours, extruded snacks and cereals.

WHOLE FAT SOY FLOUR

Whole fat soy flour, essentially ground whole soybeans, can be prepared as enzyme active or inactive. Enzyme active soy flour is the ground, dried, but uncooked soybean. This flour is excellent as a dough conditioner for baking and can be used in the production of soymilk or tofu, as mentioned above. The inactive flour is produced by grinding toasted or extruded whole soybeans. This flour can be used in food formulations requiring additional protein or water-binding; and in products such as cheese substitutes, gravies, sauces, meat analogs, pasta and baked goods.

The best way to make the inactive whole fat soy flour is simply to process the whole soybeans in the extruder and cooler (drier and conditioner). The coarse whole fat meal produced this way can then be ground with a standard flour mill.

SECONDARY "PROCESSED" SOYFOODS

SOYMILK BEVERAGES

Soymilk beverages can be made with either regular, non-UF treated soymilk, or with reconstituted UF treated soymilk. Depending on the desired product, one can produce a milk substitute, a shake, a lite drink or a cream. Products are formulated with the addition of varying amounts of water, sugar, flavors and/or flavor enhancers.

The UF treated soymilk should be easier to digest as most of the undesirable raffinose and stachyose sugars have been removed during the UF process.

TOFU VARIATIONS (Meat Substitutes)

The texture and character of tofu can be changed easily by altering the size of the curds, the pressing time and subsequent flavoring or heating. As a result, more meat-like textures and flavors can be produced.

Extra-firm Tofu: Regular tofu that has had additional pressing

time, resulting in more protein, less water content and a chewier texture.

Flavored tofu: Regular or firm style tofu which has been flavored after being made. Flavors can be added by marinating or soaking tofu in flavoring mix for one hour.

Baked tofu: Extra-firm style tofu which may or may not be flavored and which is baked to produce a drier, chewy textured tofu.

Fried tofu: Deep-fat fried regular or extra-firm, plain or flavored tofu, in cutlet, burger or nugget form. Produces a light brown, chewy tofu.

Frozen/thawed tofu: Tofu which has been frozen, thawed and slightly pressed to remove excess water. Has consistency similar to rehydrated texturized soy flour.

TEMPEH VARIATIONS (Meat Substitutes)

As with tofu, tempeh's character can be easily changed by altering its shape, form or flavor, producing a more meat-like product.

Flavored tempeh: Tempeh which has been marinated or flavored to resemble prepared meats such as bacon, burgers, etc.

Grated tempeh: Tempeh which has been grated and which can then be used to form patties, cutlets, meat balls, etc.

Crumbled tempeh: Tempeh which has been crumbled to serve as a ground meat replacer in recipes.

Fried tempeh: Deep-fat fried tempeh, flavored or plain, used as a meat or chicken substitute.

YOGURT

Producing yogurt from soymilk is very similar to producing yogurt from cow's milk. Standard yogurt cultures can be used, but experimentation with different strains is recommended. Also, because yogurt cultures need carbohydrates to flourish, and soymilk is naturally lower in simple sugars than cow's milk, additional carbohydrates need to be added for proper culture development. This can be sucrose, glucose, honey, fruit juice or any other available simple sugar. No special processing equipment is needed other than an incubating chamber.

To either regular or reconstituted soymilk (@ 8.5 to 10% solids) add 5-6% additional sugars, and heat to pasteurize @ 88C for 20 min. Homogenize, cool to 40.6C and add culture (lactobacillus acidophilus and/or bifidus and/or other recommended at 1% of weight). Mix well and pump to container or tank. Incubate for 5-7 hours @ 40.6C, or until pH reaches 4.4±.1 Cool to 0.6C to 3.3C. (See Figure 84).

Flow Chart for Soymilk Yogurt

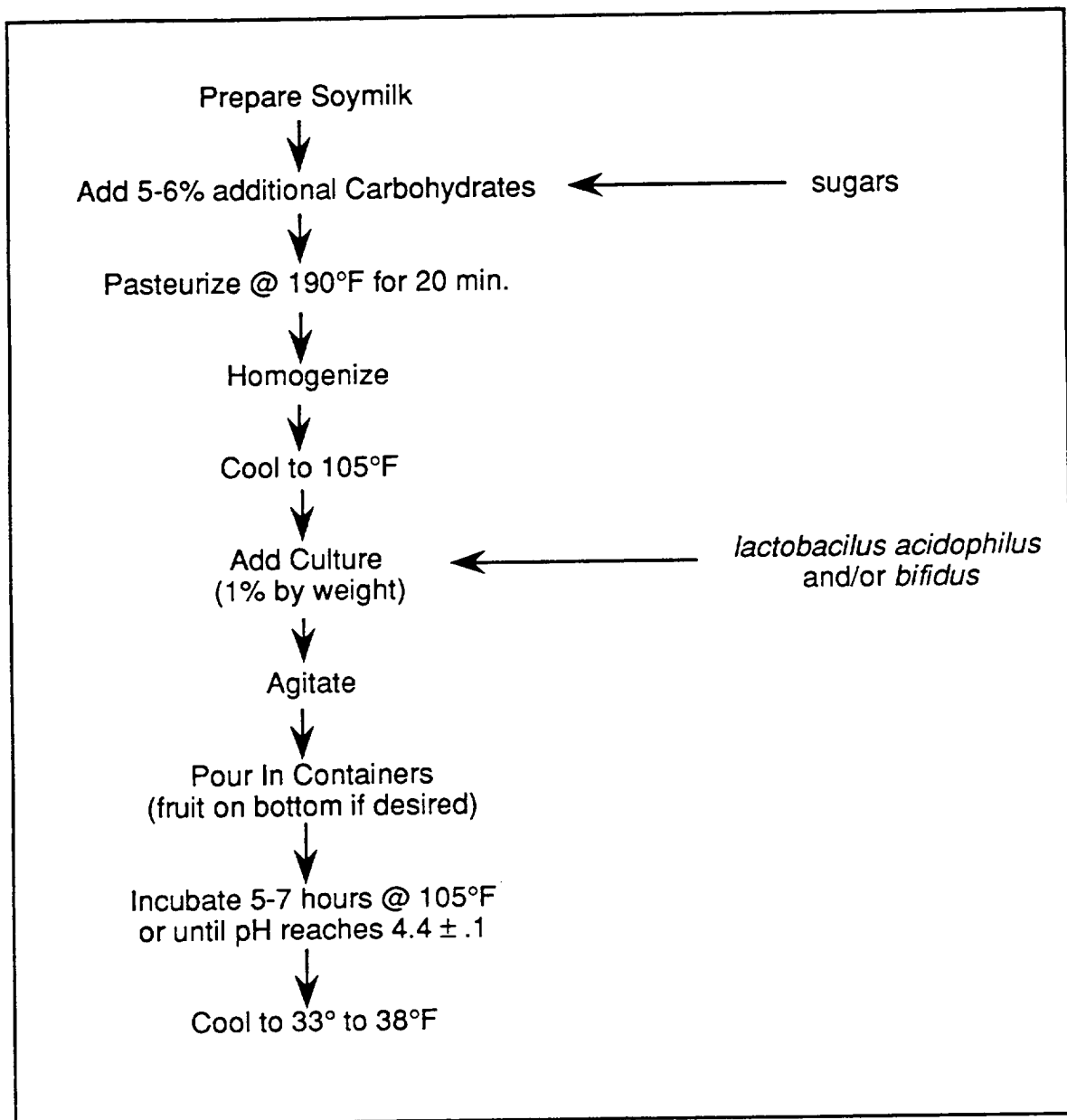


Figure 84

SOUR CREAM / CREAM CHEESE ALTERNATIVES

Soymilk yogurt can be strained or run through the UF system to produce a sour cream or cream cheese substitute, depending on the type of culture used, the final pH and the amount of water removed.

FROZEN DESSERTS (ICE CREAM SUBSTITUTE)

An excellent nondairy ice cream substitute product can be made using a high solids soymilk to which sugars and a stabilizing system have been added. Small-scale home type processors should be able to produce a good product.

To get as creamy a final product as possible, a thick soymilk — one that has been made with a slightly lower water to bean ratio than usual should be used. Additional fat may be incorporated in the mix for creaminess and better freezing characteristics. This fat could come from soybean oil or other vegetable oil.

The product shown in Figure 85 can be produced either in a small batch processor used to make ice cream at home or in a small shop, or it can be scaled up to be run in a commercial freezer. Flavorings which tend to add additional solids such as chocolate or fruit can greatly improve the final product. Vanilla is the hardest flavor with which to achieve satisfactory results. The expected overrun with soymilk-based frozen desserts is less than that of ice cream, about 40%. This can be improved with the use of different stabilizing systems.

MARGARINE

Instead of taking the conventional approach of hydrogenating the soybean oil to make margarine, research should be undertaken to investigate methods of physically composing a margarine substitute using food technology. Perhaps this could be accomplished by combining the oil with a finely ground soy flour, UF concentrated soymilk, or both. This should result in the formation of a high-fat spread similar in appearance and texture to margarine.

TEXTURED SOY FLOUR

Partially defatted soy flour can be re-extruded in the same extruder (with modifications) used to initially process the soybeans to produce random or same-sized chunks, pieces or flakes of textured soy flour. Other ingredients may also be added to the soy flour prior to texturizing, such as starch or wheat to create products for different applications. Such uses would be as a meat-analog base, a ground beef replacement, a chicken substitute, or a snack food or cereal.

In order to accomplish this, the extruder would need to be fitted with all or some of the following auxiliary equipment: a compression head used to force the extruded material through smaller holes to produce pellets or chunks; a flaking roll to produce

Flow Chart for Soymilk Ice Cream

Makes 1 kilo

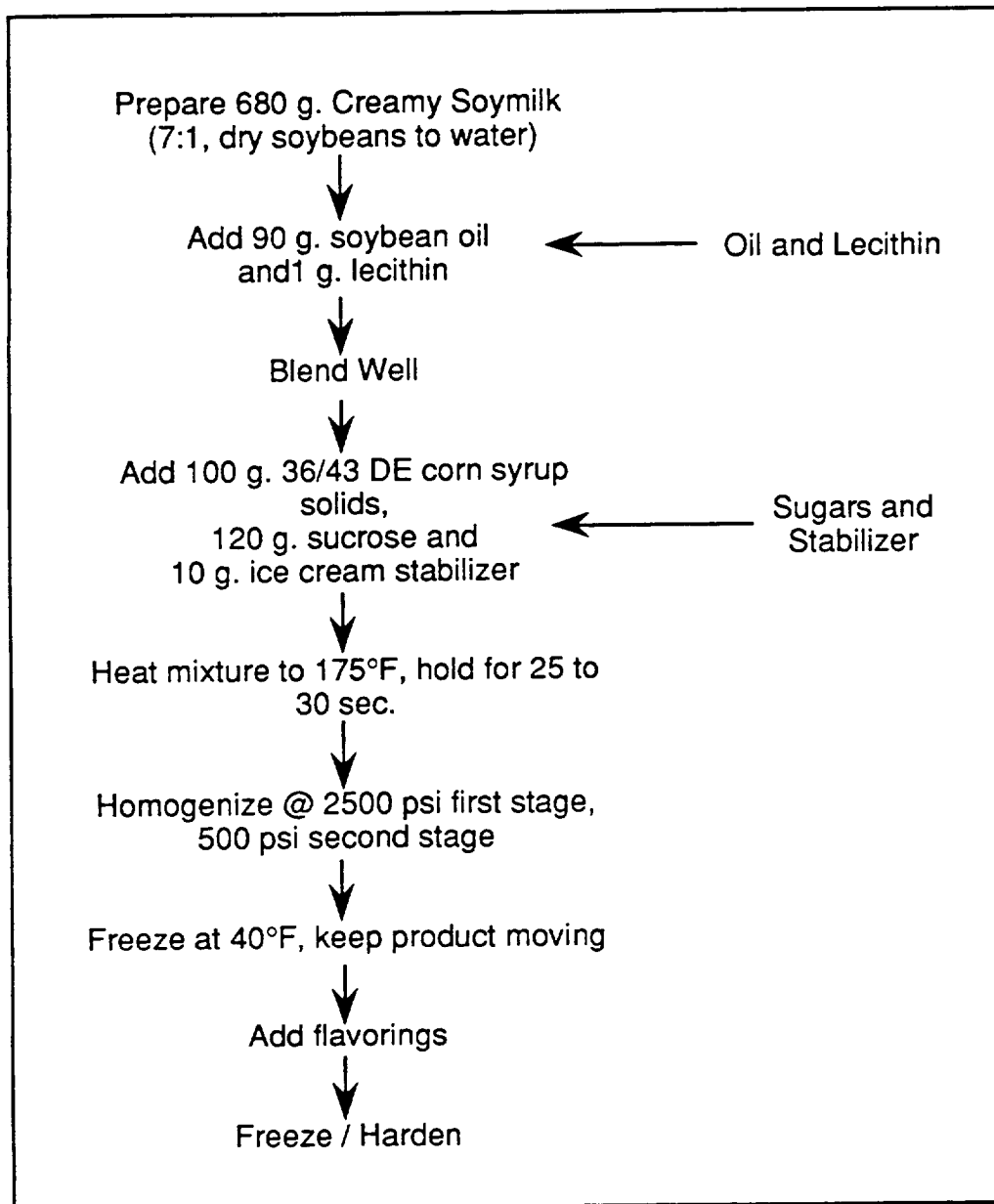


Figure 85

flakes, crispies, balls or custom shapes; a particlizer/cutter used to reduce gelatinous extruded material into particle sizes for conveying or handling; and a cutter head, used to shape mixtures into large pellets, chunks or customized configurations.

The INSTA-PRO extruder mentioned earlier as the extruder of choice for processing the dry soybeans can be adapted as mentioned. If we were to choose an smaller extruder due to the issues raised earlier in relation to size of the processing unit, it should have the capabilities mentioned above as well.

PROCESSING SOYBEANS FOR PRIMARY SOYFOODS WITH EXTRUDER

It is possible, as mentioned in the above, that an extruder can be used in place of the grinder and cooker for processing soymilk and tofu. Extrusion/expelling is already a proven technology for processing the soybean into meal and oil. Whether or not a small scale extruder can suffice for preparing the soybean for aqueous extraction will need to be evaluated.

In particular, what needs to be determined is whether or not a sufficiently high degree of protein dispersibility (PDI) can be maintained in the soybean after extrusion cooking. It is important to understand fully the correlation between temperature, time and PDI when using an extruder. This relation is well understood when processing soybeans in the more traditional manner of grinding with water. The extrusion cooking process would be accomplished with no additional water. This is where the major difference occurs. Water would only be added after the soybeans have been cooked.

The flow chart in Figure 86 depicts how such a system could operate. It may also be possible to design and build a single extruder/expeller/aqueous processing unit which, by changing the configuration of the processing unit, and by injection of steam and/or water at the different stages, can be used as the main soybean processing system to produce meal, oil and soymilk. Additional research would be needed to adequately define the design parameters of this type of unit.

With regard to CELSS application, soybeans performs several very important roles apart from its function as a source of nutrition. These roles include providing a majority of the meat replacement products, at least half of the beverages, and many other foods that make meals a pleasurable experience, including frozen desserts, puddings, yogurts, spreads, dips, and non-dairy cheeses. This multitude of roles is possible largely because of the functional properties of soy protein.

The oil content of soybeans is about 18%. Based on estimates presented earlier in this report, soy would contribute about 30% of the total fat requirement. This fat can be consumed entirely as part of the soy product spectrum, or a portion can be expelled and used to make various soy oil products, including spreads and dressings, as well as used as an ingredient. Expelling on a small scale would recover approximately 50 to 70 percent of that depending on whether the process was done

Processing Soybeans for Primary Soyfood Products with Extruder

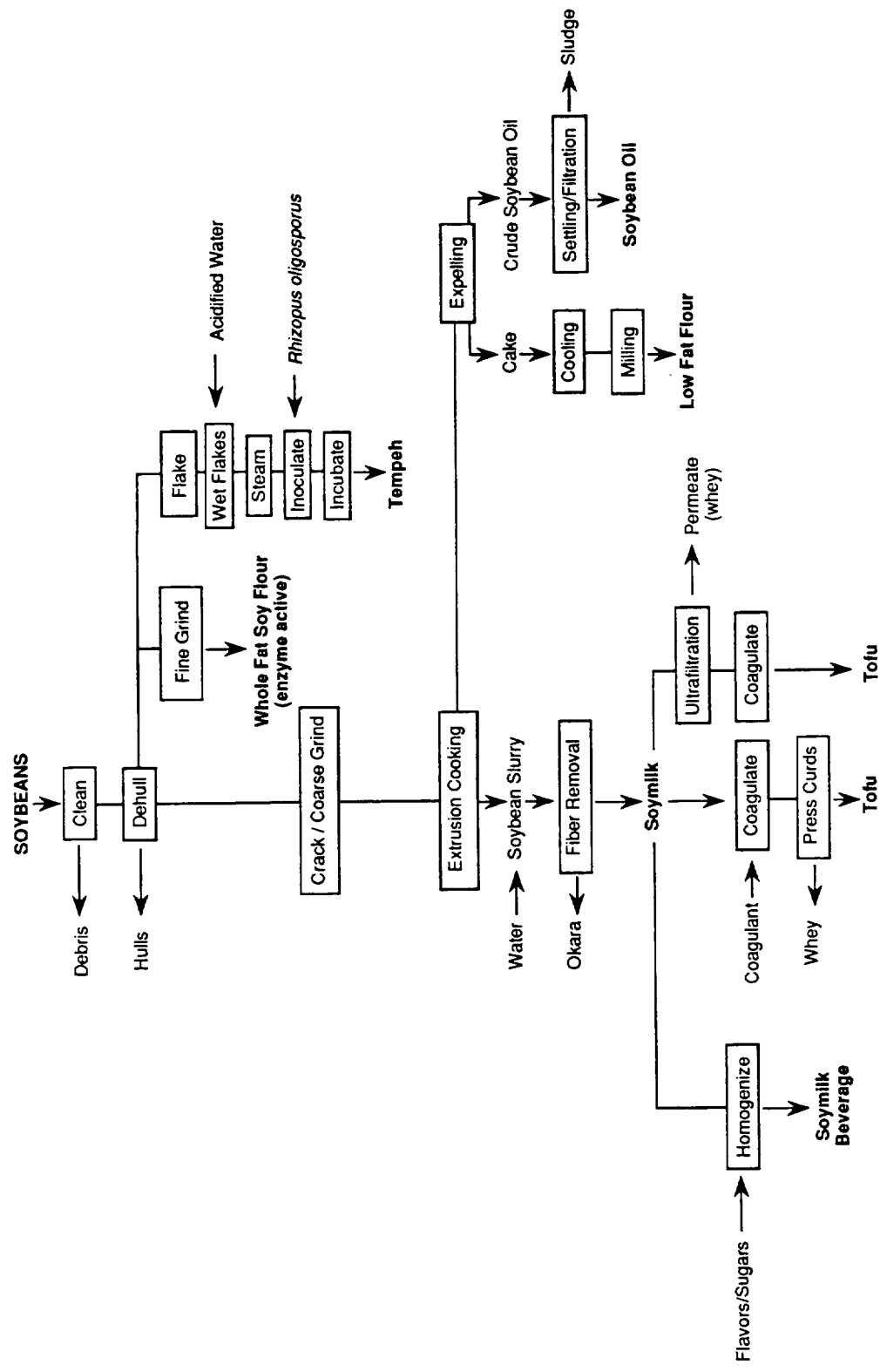


Figure 86

cold or hot. Expelling equipment is necessarily heavy and energy intensive because of the pressures required. The unknown is the impact of expelling on the capabilities of soy in terms of tempe, soymilk, and tofu production. Additional information is needed on possible technologies which could permit oil recovery without interfering with valuable functional properties. Based on these considerations, it is recommended that for CELSS operations, pending resolution of these concerns, edible oil recovery processes be focussed on crops other than soybeans.

FASI has been granted Phase III funding by the North Central Soybean Research Program to conduct a more detailed review of new soybean technology and the needs of the space program. As part of this program the FASI team will be examining new technologies being studied by the USDA, the University of Illinois, Texas A&M, as well as industry, aimed at both the functional properties of soy protein, soy products, and the recovery, processing, and utilization of soy oils. In view of these efforts it is anticipated that many of the concerns addressed above will be resolved in the near future.

MATERIALS BALANCE

Based upon the assumption of a twelve person crew, it has been estimated, based upon the calculation of needed fat in the diet, that it will take approximately 236 kilos, or 520 pounds of dried soybeans to supply the necessary fat for 30 days. Because of the relatively low amount of fat in the soybean, this amount of soybeans would provide approximately twice the amount of protein required for the period. But at this point, these calculations are only meant to serve as a reference in regards to the size of systems needed. As a result, the information below shows how much product will be produced by the processing of 100 kilos of soybeans, which would need to be done approximately every 10 to 15 days.

The following materials balance is based on the soybean composition below:

Typical Whole Dried Soybean

Protein	39.2%
Fat	17.2%
Carbohydrates	25.2%
Crude Fiber	5.3%
Ash	5.1%
Moisture	8.0%

100 kg of soybeans processed to make flour and oil will produce:

79.1 kg	low fat soy flour
12.9 kg	crude soybean oil (assumes a 75% extraction rate)
2.0 kg	soybean hulls

100 kg of soybeans, plus 800 kg of water processed to make soy-milk or tofu will produce:

760.0 kg	soymilk (8.6% solids, 91.4% water)
140.0 kg	okara (35 kg soy solids, 105 kg water)

If further processed into tofu, the 760 kg of soymilk will yield:

250.0 kg	firm tofu
510.0 kg	soybean whey

100 kg of soybeans processed into tempeh will yield:

200.0 kg	tempeh.
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LOUVER DRYER

The FASI louver dryer has an air flow that is satisfactory for handling wheat and dry soy beans. It also functions effectively as a thresher. The following paragraphs describe design parameters relating to drying capability.

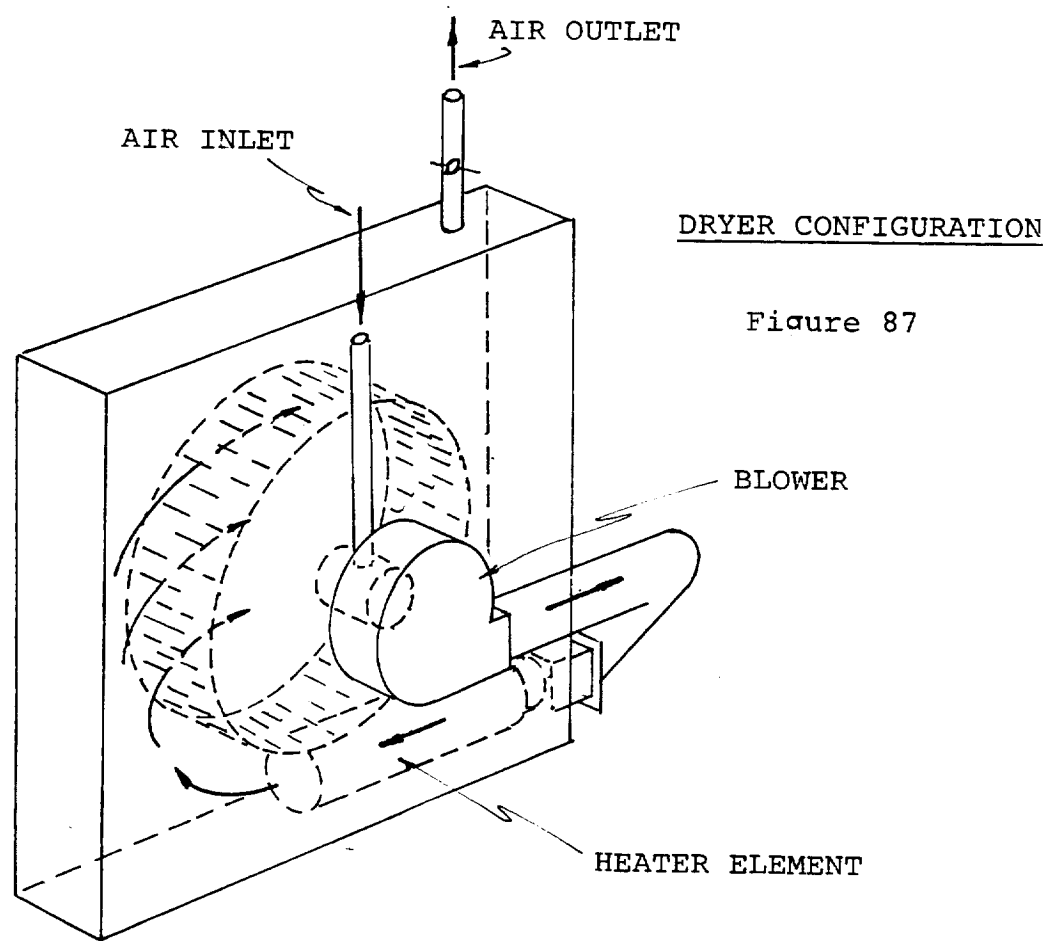
Various heating options have been examined. A once through system would be totally uneconomic, given the quantity of air required to lift and recirculate materials. It would also be impractical to release such a high heat load into a confined space. A system is required to recirculate the bulk of the air.

The preferred design is shown in Figure 87 providing an air flow diagram as shown in Figure 88. The heater is a standard clothes dryer electrical element. It is a complete unit consisting of a circular duct with an electrical resistance coil suspended in the air passage by insulators. Heat regulation for the prototype is provided by an inexpensive thermostat.

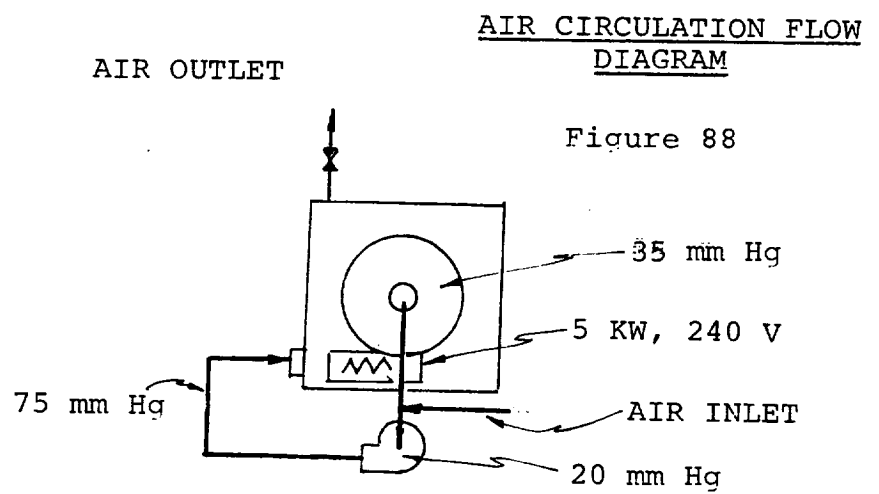
Insulation is necessary to prevent excessive heat loss. On start-up, to preheat the unit, all the air should be recirculated. During drying, some air from the dryer plenum, which is under positive pressure, would be permitted to vent through the exhaust damper. To compensate, air is drawn in through the open make-up port which would be at atmospheric pressure during full recycle, but whose pressure would drop as air is bled off through the exhaust damper (see Figure 89). The amount of exhaust would normally be controlled by the ratio of relative humidity to exhaust air temperature in order to maintain optimum drying conditions.

HEAT TRANSFER FOR THE CELSS FOOD SYSTEM

There are equipment items and appliances available for heating foods in the 175 to 205C range, designed specifically to meet the needs of individual foods (such as baked potato) or narrow



LOUVER DRYER



categories of products (such as deep fat fried foods). Some of these could be adapted for CELSS. And, once detailed process and preparation schedules are established with quantities and frequency of use firm, some may be selected. A major criterion in the evaluation of heating equipment capabilities and designs was minimization of the number of items needed, while not downgrading performance, versatility, safety, or quality of the prepared food nor increasing operational complexity.

The common food and intermediate ingredient heating modes required for CELSS include: cook/steam, bake, fry, puff, toast, grill, broil, and roast. In terms of equipment capabilities, these needs are:

- Moist heat - use of a confining vessel and/or condensing steam
- Dry heat - to produce a browned, slightly hardened product surface
- Convected dry heat - to heat multiple small pieces without stirring
- Rapid internal heat - for puffing action
- Surface heating - for browning and crisping as well as cooking foods

Two ovens, each basically capable of meeting the above heating requirements, are recommended. The rationale for two includes recognition that two or more ovens units are likely to be needed and used simultaneously to meet processing and food preparation quantities, numbers of products and ingredients, and schedules. Although similar in most capabilities, each oven has features favoring its use for some tasks (such as microwaves for puffing, and high velocity air for stir-frying).

One of the ovens recommended uses microwaves plus convected hot air and radiant heat as required. Microwave energy usage for food heating or cooking is efficient, safe, and for nominal loads,--rapid. However, microwave, by itself, does not generate typical flavors or surface characteristics, and its mass dependency offsets its rapid heating potential. To compensate, other heating techniques for sequential or simultaneous use are incorporated. The specific design recommended for CELSS features a usable oven cavity 94 cm wide, 51 cm deep, and 25 cm high; microwave power from six 1.25 kw modules through three W-shaped antennas near the ceiling, and three near the floor of the oven; radiant heat through the same antennas; and forced hot air heat through use of one or more remote, shielded fans. The recommendation is based on the unit's overall simplicity and versatility in being able to provide three different modes of heating simultaneously.

Most microwave cooking can be accomplished in a straight forward manner in a shallow pan with foil, flexible film or paper towel--ing as a partial cover to prevent excessive moisture loss or scorching. There may be instances where steam per se is preferred. A successful method for implementing this is through the use of a microwave transparent vessel, shown as Figure 26 (page 66), into which, product in a perforated metal pan and some water are placed. The water is heated by the microwaves, con-

verted to steam that passes through the perforations to the inner product. Since the perforated metal pan would be microwave opaque, the product would cook by steam alone. If a polymer or glass microwave transparent container were used, the products would cook by both steam and microwaves.

Microwaves appear to be a preferred technique for producing puffed products where formulations are prepared fundamentally as a copy of popcorn; i.e., a case hardened, moist interior bit that expands following internal heating.

The second oven recommended for CELSS is based on tests of the American Harvest unit which circulated very high velocity heated air over and around food. Conventional hot air convection ovens have an air flow velocity in the neighborhood of 60 meters per minute. By comparison, the manufacturers of this oven cite air velocities at about 670 meters per minute. Because of the newness of this oven, and the absence of widespread experience in its use, assessment of its applicability to CELSS was based on a variety of tests. Incentives for testing were claims of cooking speeds rivaling those of microwaves; concomitant development of color, surface texture, and flavor that are frequently absent with microwaves; and the unit's light weight, compact, and component accessible design. A significant factor was the possibility of broad performance using a single energy source.

Test runs were made with the American Harvest oven, using as accurately as possible, CELSS available ingredients and appropriate substitutes, covering a wide range of products and assessing the heating requirements listed above. These tests were sufficiently comprehensive and successful to conclude that a high air velocity oven such as the American Harvest unit or its equivalent should be on the equipment list for CELSS. The American Harvest-type units on the market seem limited to serving approximately four personnel. For a crew of twelve, significant redesign will be required. Two concepts have been explored on a concept basis. One utilizes the "cyclonic" air flow patterns common to the American Harvest and Decosonic units. The other uses straight-through air flow with blower and heater external to the oven chamber.

Clamps to replace stepped supports for racks would facilitate use in zero-gravity.

Lexan covers are desirable for hot appliances to prevent burn injury to space crew members. Lexan, however, has temperature limits. In the event of a thermostatic control failure which would permit the heater to remain on, the heat output could produce a temperature in the oven possibly reaching or exceeding the melting point of the Lexan cover. Accordingly, it is recommended for CELSS applications that a thermostatic cutout be incorporated in the heater circuit to cut power to the resistance coil if oven temperature exceeds a predetermined temperature.

FRENCH FRY PRODUCTION

SHOESTRING CUTTING

A generous portion of french fries requires two raw 200 gm potatoes. To provide sufficient for a crew of twelve would require shoestring cutting 20 to 25 potatoes. Based on our evaluation of manual and commercial french fry cutters, which entailed considerations of cube, weight, ease of use, and clean-up, a non-automated system appears the most practical approach.

The powered units include the Cuisinart-type cutter which cuts the shoestrings on the short axis of the potato, and the Kitchen-Aid, which cuts with the long axis. There are various manual cutters, most of which force a potato through a squared grid of thin blades. Two of these were evaluated with the idea that they could be incorporated into a KitchenAid-type cutter.

The two cutters tried were evaluated, an Italian Unit, and a German unit. The Italian unit, fabricated mainly of plastic, provided for interchangeable 7 and 9 mm grids. It also incorporates a guide trough which makes the potato easier to insert and cut without having to manually prevent its cocking. In spite of a long lever, it requires considerable force (i.e., a strong adult) to operate it with the 9mm grid, and even more with the 7mm grid. Because of the force, the back of the potato is close to its crushing point, even with a flat area cut to permit insertion of the potato into the unit.

The German unit, mainly aluminum construction, had only a fixed 9 mm grid. It accepted the same size potatoes as the other unit, but had a better mechanical advantage, requiring less force for operation. This was made possible by using two strokes, via a ratchet mechanism. Both the Italian and German units could be washed by rinsing the entire unit. Both designs could be relatively easily adapted to fit the elliptical throat of our cutter design.

FRYING

Additional tests were conducted with oiling and dry convection cooking techniques to examine in greater detail the parameters of french frying. MacDonald's fries were used for comparison.

Potatoes representing three different varieties, white, red, and Russet, were sliced into 5mm fries using the Cuisinart cutter. Each variety was washed and dried separately, immersed briefly in oil and spun in a salad dryer to remove excess oil. The fingers were placed on the base tray of an American Harvest high air velocity oven with a hold down grid on top. Previous experiments used high temperatures to correspond with commonly used deep frying procedures. Observation of normal deep fat frying indicates that the latent heat of evaporation is sufficiently great that if the system cannot provide at least three kilowatts per kg of fries, the oil temperature very quickly drops to about 100°C while the potatoes cook and water is driven off as steam. As the evaporation rate decreases, the oil temperature increases, and

browning resumes.

Frequently, in food service operations, the fries are removed from the oil for a minute or two to permit additional water to evaporate, and for the oil to regain temperature. They are then placed back in the oil to finish the frying process.

To simulate frying conditions, the total mass of fries in the oven (rated at 1500 watts) was approximately 600 gms. The temperature was set at 120°C. After 15 minutes, the fries were cooked but still limp, not browned. They were removed from the bottom pan, placed on a raised rack in the oven for greater air contact, and allowed to cook for another 5 minutes. At this point, the fries had a very pleasing brown appearance. Only a few slivers were dark brown. The fries were crisp, not at all soggy, and there was no oil present in the tray. Cleanup was minimal. The amount of oil on the fries was just right. The only objection might be that they were a little dry. For the same weight of fries, a temperature setting of 135°C for 15 minutes would probably deliver perfect fries.

The conclusion was that it is quite feasible to dry-cook french fries that are virtually indistinguishable from the conventional deep-fried product. Clearly, the heating capability of the frying system should be taken into account in determining the size of the batch to be fried. Conversely, it should be possible to relate cooking conditions with some precision and program a dry fry cooker for the mass being cooked.

In terms of product differences between the three varieties, the white and red potatoes were about the same in browning and crispiness. The russets were crispier than either.

USE OF CYCLONIC HIGH AIR VELOCITY OVEN FOR MAKING FRENCH-FRIES

Tests were conducted with an American Harvest Oven to investigate its capability for cooking french fries. The convection oven is considerably slower than actual deep fat frying. While the quality of fries produced in earlier tests was very acceptable, they did not always match the degree of crispness observed in commercially produced fries. The test was to determine whether the limitation was the actual heating capacity of the unit or convective heat transfer rate constraints.

The conclusion is that heat transfer is the limiting factor. The initial high temperature of an oil bath used to cook fries drops to just above the water boiling point when raw fries are plunged in, and only climbs again when the total heat input exceeds that required to evaporate the residual water in the potato tissue. Conductive heat transfer from oil is very high and, on a conventional range top (or an even hotter gas burner), the evaporative capacity of the fries will nonetheless exceed the input capacity of the heat source. This is not the case with a convective oven.

Table 8 shows cycling times for an American Harvest Jetstream Oven during several french fry test runs. The cycle time measurement is the time the heater element is on and the time that it is

off. The fact that the heater turns off shows that moisture in the fries cannot be evaporated fast enough to load the heater continuously. That the cycling time changes indicates only that the evaporation rate slows.

Table 8. JETSTREAM OVEN TESTS - FRENCH FRIES

gms	Start		End		Time Temp		@ 5 min	@ 20 min
	gms	%	gms	%	min	°C	sec	sec
340	160	48	8.4	2.5	24	107	11/7	6/9
284	135	48	7.0	2.5	24	107	15/7	7/9
227	99	44	5.6	2.5	21	121	12/7	7/8
170	74	44	4.2	2.5	21	121*	11/8	8/9

NOTES;

Fries were cut from small white potatoes

Fry cross-section - 7mm X 7mm

Actual oven temperature approximately 14 C° higher than setting

* indicates fan set at LOW speed, 140W v 230W @ high setting

Heater output 1030W

Oil applied by agitating fries in ZipLok bag with measured quantity of oil

Fries placed in single layer on high rack with second rack resting on top as a restrainer

Increasing the cooking temperature makes a difference to the cooking time. Since heat transfer is linearly proportional to the log mean temperature difference, the reduced cooking time would be expected.

The absence of crispiness in a convection oven could be attributed to the chips' being essentially cooked rather than fried due to the slower air-potato heat transfer. One alternative solution would be to accelerate the cooking time to that of deep fat frying, e.g. about 10 minutes instead of 21, by raising the temperature to 230°C or more, at which point the tips of the fries would tend to burn. Frying temperatures of 110°C to 120°C avoid this, but tend to result in higher oil absorption, and may not crisp well. Fryers in commercial operations are commonly run at 177°C to 191°C to minimize oil pickup by the product.

Another consideration for CELSS operations is to increase the surface area of the fries. Fries cut on the K-Tec unit have a cross-section resembling a "V". When these were tested in the American Harvest oven, they crisped very acceptably to produce a fry with a texture and flavor approximately half-way between a french fry and a potato chip.

A third possible solution, which might be cumbersome for CELSS operations with small crews, but which could have advantages, for resupply modes, would be to pre-dry the cut potatoes prior to frying. This is standard practice for potatoes supplied to the fast food industry for french frying. Following cutting and blanching, these potatoes are dried to about 60% of their original weight.

An even more attractive long term alternative that should be especially compatible with the stable intermediate concept would be supplying potatoes in a compressed, low weight form that would allow the space crew to formulate and create products as needed. This could allow extrusion of fries and or chips with a predetermined moisture level suitable for frying in convection systems.

HIGH AIR VELOCITY CONVECTION OVEN DESIGN PARAMETERS

A series of tests was conducted with the American Harvest Jetstream oven to characterize the air flow patterns in the chamber from which to establish some parameters for a custom design. A pitot tube was used to determine air velocities and air-flow directions.

OVEN EMPTY

The maximum velocity at the periphery with nothing in the oven and no racks was 960 cm/sec.

The velocity increased towards the vertical axis of the chamber, reaching a maximum of 2,000 cm/sec at 11.75 cm from the outside surface of the chamber.

The flow direction was essentially equatorial, with no perceptible helical deviation.

At low speed, when the motor draws approximately 60% of the full-load current, velocity readings were 66% across the same profile.

OBSTRUCTED AIR FLOW

With two racks in the oven, the full-load velocities were relatively unchanged, except the maximum velocity dropped by 25%.

Low-speed velocities plummeted to less than 10%, on average, of the low-speed empty oven readings. Clearly, the presence of items in the chamber will disrupt air flows even more.

Based on laboratory evaluation of the American Harvest Jetstream Oven, the design of an oven for CELSS use should incorporate the following features.

1. COMPACTNESS - The American Harvest design is light and compact, and is relatively easily stowed when not in use. With easily stowed expansion rings, it can be expanded to approximately 300% of its original capacity.
2. EASE OF CLEANING - Another desirable feature of the American Harvest design that should be incorporated is ease of cleaning. Maximum temperatures are limited, so plastics and teflon coated pans are feasible, practically eliminating burn-on. Most surfaces can be wiped clean.

3. HIGH AIR VELOCITIES - Higher air velocities than those attainable with the American Harvest when foods are placed in the oven are desirable. A figure of 700 cm/sec or more should be achievable. To avoid break-up of the air flow, the oven and racks should be designed to cause a minimum of disruption, even when the oven is fully loaded. Alternative solutions include utilization of a fan or blower enabling higher static pressures, and air flow patterns less susceptible to product disruptions.

4. MOISTURE VENTING - Moisture liberated from cooking french fries in the American Harvest Jetstream oven exits between the lid and base, through the joint. At cooking temperatures, humidity levels are low, but there may be enough entrained steam to inhibit crisping of french fries. Make-up air and vent ducts would be desirable for a dry oven. Systems will be needed to capture moist, vented air and prevent cooking odors from permeating compartment atmosphere.

5. CONVENIENCE - The unit should be easy to assemble, use, and store.

6. CHARACTERISTICS - The principal foodstuffs that are likely to be cooked in a high air velocity oven are french fries, snacks, pancakes and waffles, baked potatoes and sweet potatoes, stir-fry, baked goods, "meat" analogs, and casseroles.

MODIFIED HIGH AIR VELOCITY CONVECTION OVEN CONCEPT DESIGN

Figure 89 is a concept design for a high air velocity convection oven. It is an expandable unit consisting of up to four cube-like sections, a base and fan/heater unit. It has inserts that either provide circumferential flow for stir-frying and french fries or cross-flow for pancakes and baking.

CONFIGURATION

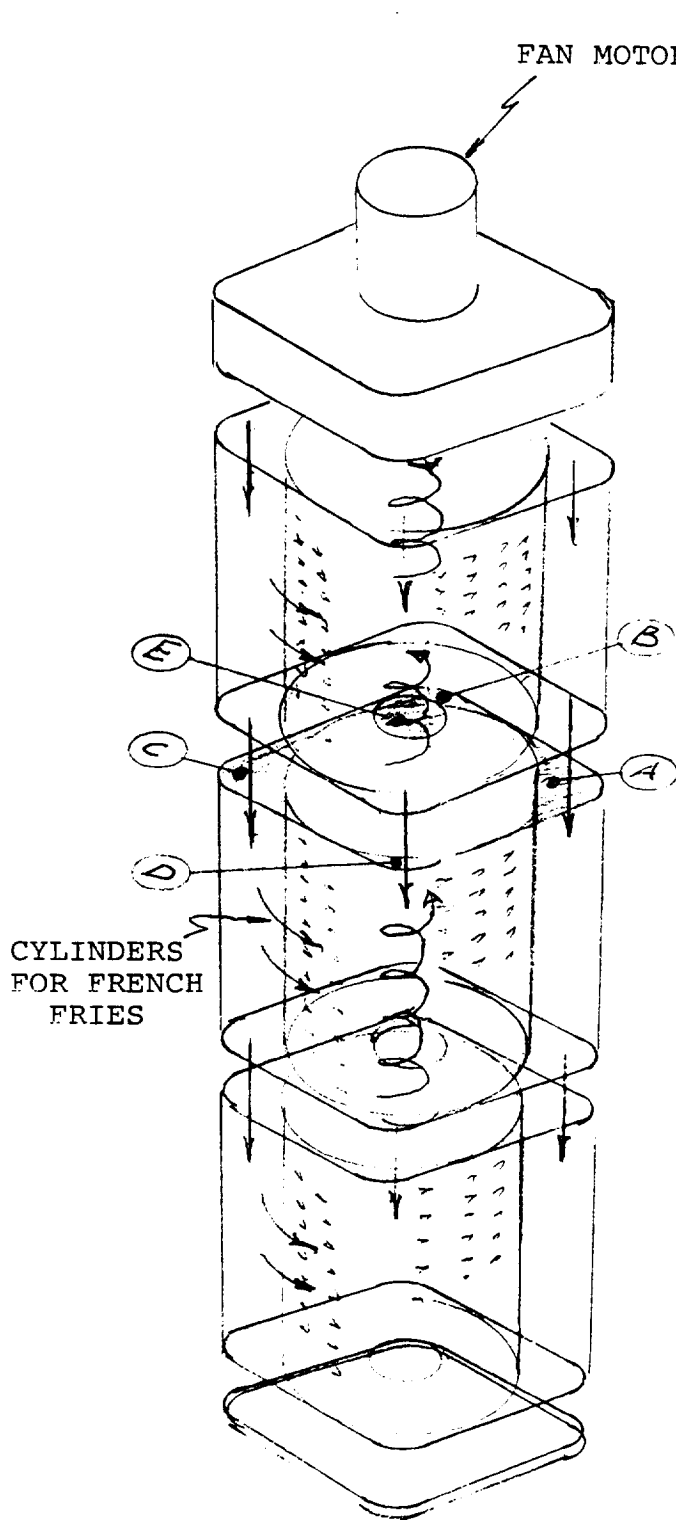
CIRCUMFERENTIAL FLOW

In Figure 89 each cube section, which is open at both ends, is made of transparent plastic which attaches to adjacent sections and the top and bottom with a twist bayonet fitting. Cylindrical inserts of similar plastic create four plenums (A,B,C,& D) down which hot air is ducted.

The cylinders have bottoms with holes (E) in them and multiple slots in the wall that induce a tangential air flow in the cylinders (Figure 91). As with a cyclone, return air forms a central vortex that spirals up through the bottom holes to the eye of the heater fan unit.

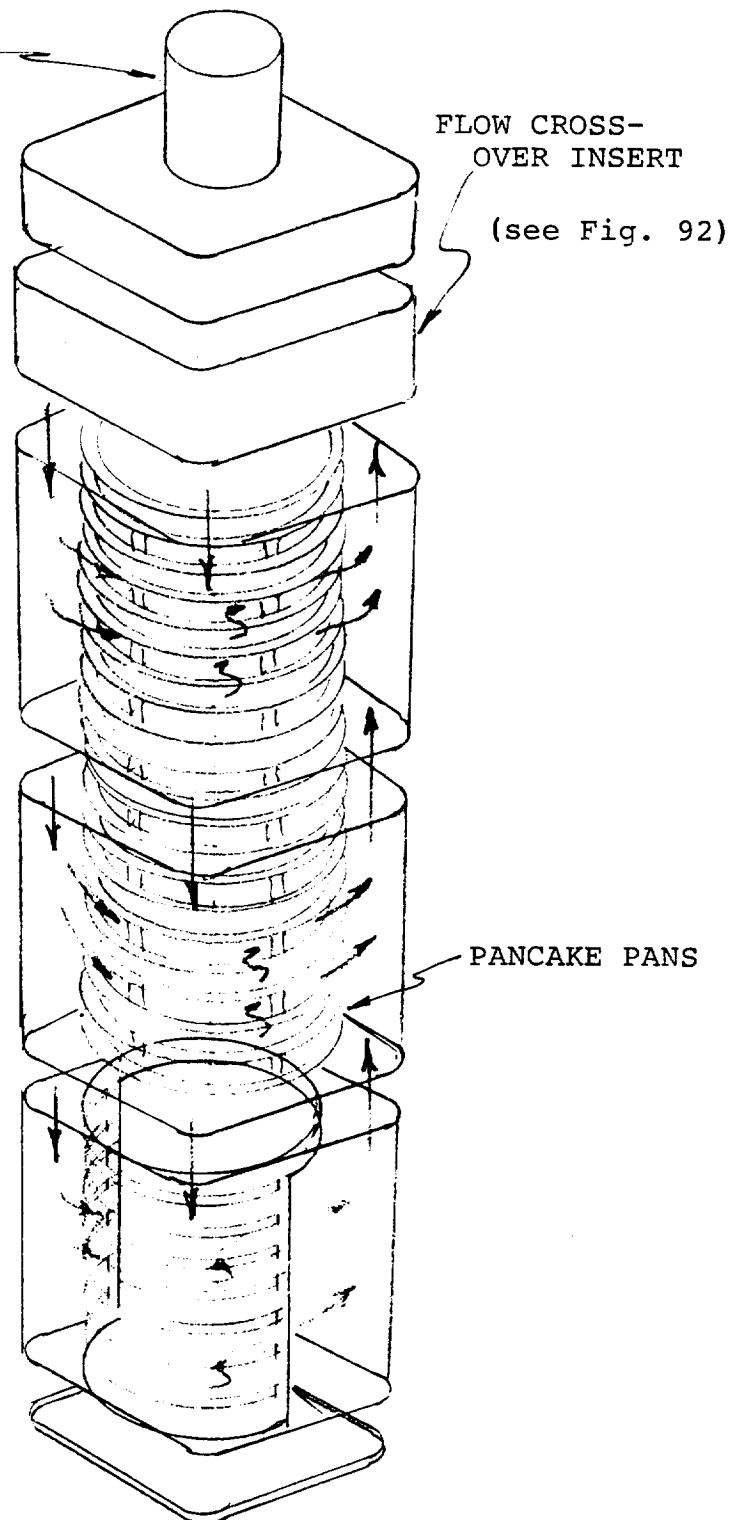
French fries or stir-fry pieces are pre-oiled and placed in the cylinders before their insertion in the cube stack. The heater/fan unit is attached making a closed system. The circumferential air flow causes the fries or stir-fry pieces to rotate slowly within the cylinders. Centrifugal force causes the food pieces to migrate towards the cylinder walls, leaving a space in the center for the return air vortex.

CONVECTION OVEN
EXPLODED VIEW



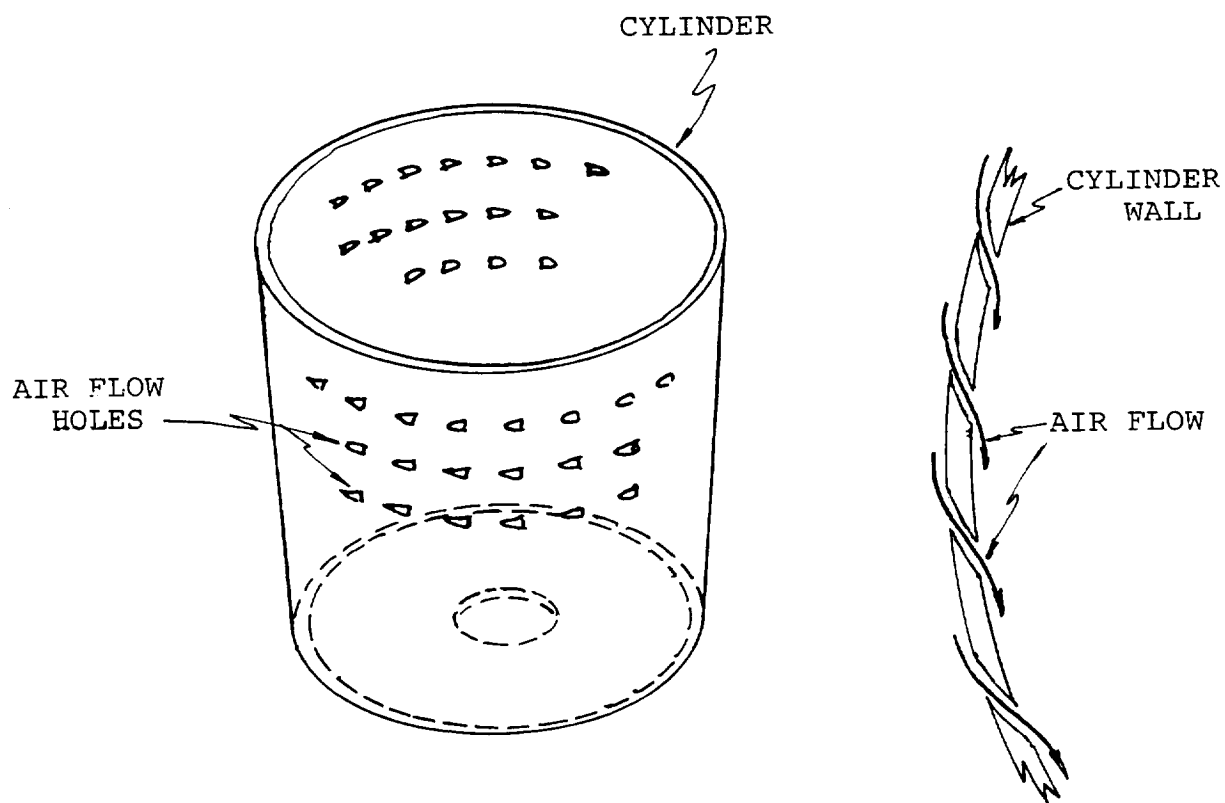
CENTRIFUGAL FLOW

Figure 89



CROSS FLOW

Figure 90



TANGENTIAL AIR FLOW CYLINDER FOR FRENCH FRIES, ETC.

Figure 91

CROSS FLOW

In Figure 90, a cross-over block (Figure 92) changes the air flow in the plenums formed between the circular insert and the square outer section so that air is ducted down two plenums and returned up the other two.

Pancakes and waffles are two unusual products that can be produced in volume in this type of oven as described in APPENDIX A.

Figures 93, 94 and 95 show two concept designs of pans for the production of pancakes. Pans for waffles would be similar in concept, but have the typical embossed pattern. A third pancake pan configuration is shown in Figure 96. The pans have identical dimensions and snap one into another. However, there are two types. Half of the pan sections have slots in the sides so that the air passing down two plenums is free to traverse the bottom pan surface and leave through the slots on the opposite side. From there the air is drawn up the return-air plenums to the fan/heater unit. The sections are made of aluminum.

The inside and outside of the pans would be coated with a durable non-stick surface. A measured amount of pancake mix is placed in a pan with a syringe before a spacer is snapped on as a lid. The process is repeated to form a stack, the height of which is dependent on how many pancakes are required. From one to four cube sections may be used to accommodate the stack which now consists of closed pans containing batter that will be exposed to hot, cooking air on both top and bottom surfaces.

The bottom section of Figure 90 contains an air-flow proportioner. Its function is simply to distribute air evenly for conventional baking of items like potatoes. Other possible applications of the oven are:

Bread: The centrifugal flow sections without the bottoms can be used to form a long, 60 cm cylinder suitable for cooking all-crust baguettes without a pan. A moderate centrifugal air flow will cause the baguette to center itself along the axis of the cylinder. However, the return air vortex would tend to drive the baguette towards the fan inlet. To adapt the stir-fry system for bread baking, air would be required to exit in a balanced flow at the four end spaces between the cube sections and ends. Figure 92 shows a bread baking adapter to fit between each cube section. The blocks direct air from two plenums to half the stir-fry cylindrical section surface and draw the return air off at the cube interfaces.

HEATER/FAN ASSEMBLY

Figure 97 shows the heater/fan assembly. The fan is conventional. In an interesting modification, heat may be provided by electrical resistive heating coils enveloping the fan periphery or possibly by the fan blades themselves. Preliminary calculations show that it may be possible to obtain a 2,500 watt heat transfer if a composite material can operate at 300° C or more.

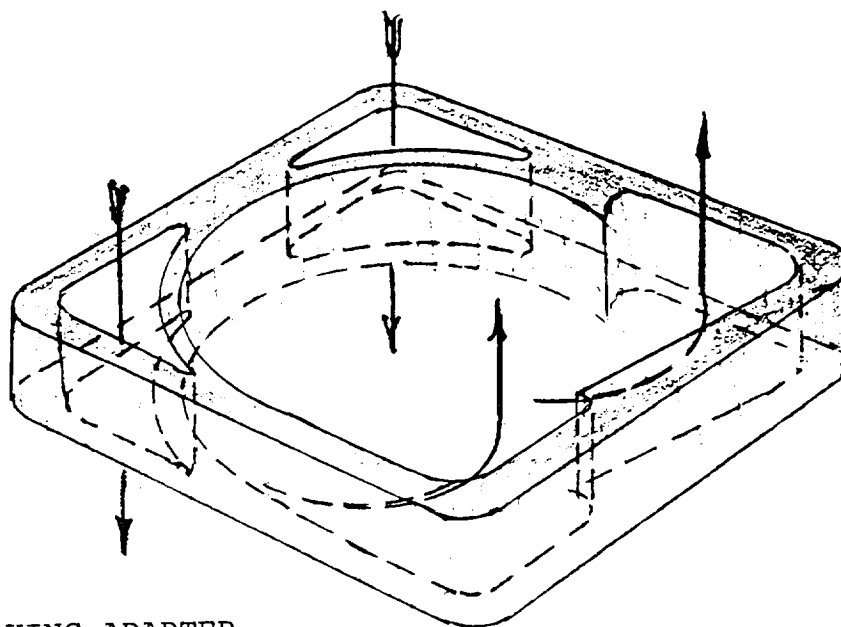
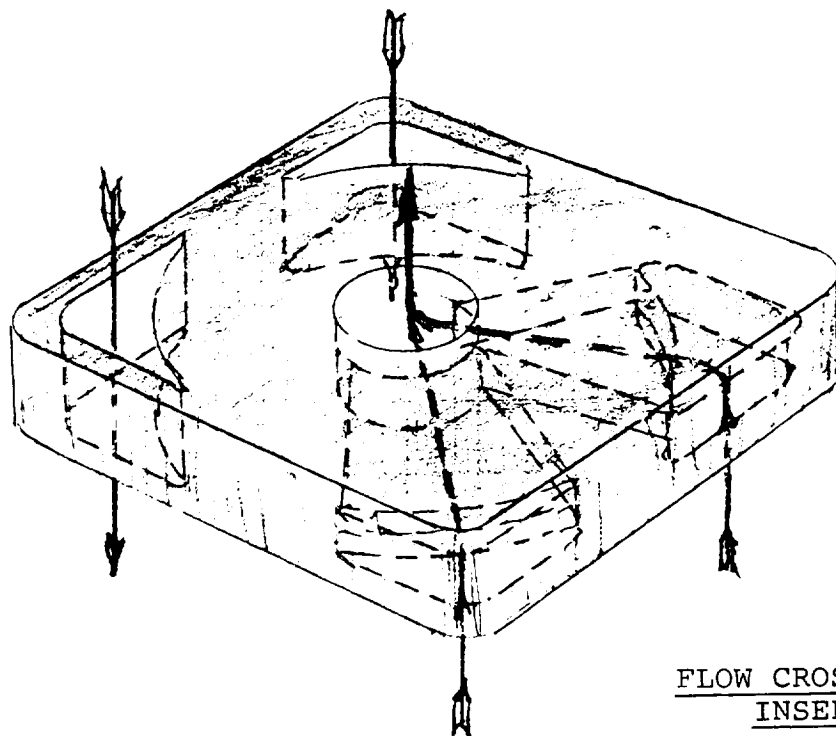
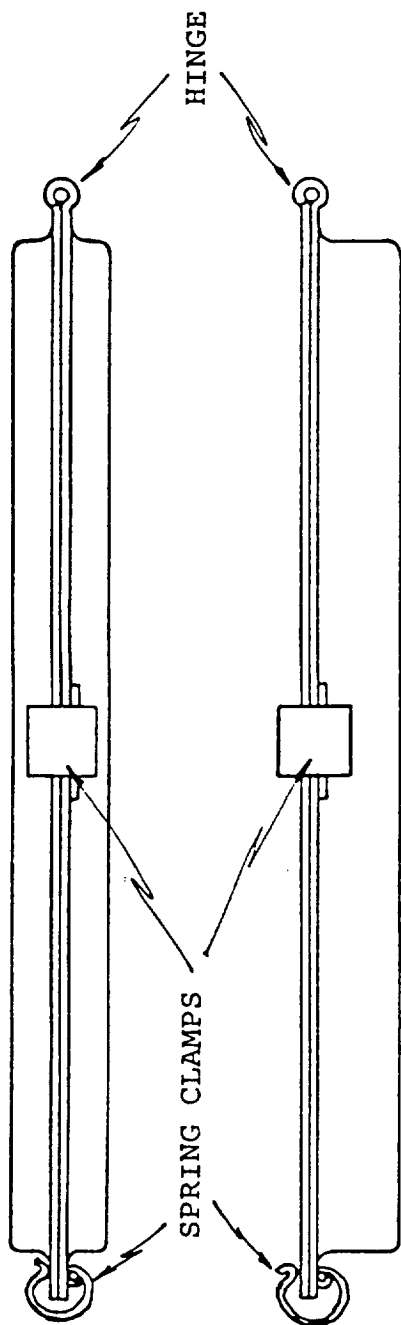


Figure 92

CLAMSHELL CONFIGURATION



FLAT-LID CONFIGURATION

Figure 93

PANCAKE/WAFFLE PLATEN

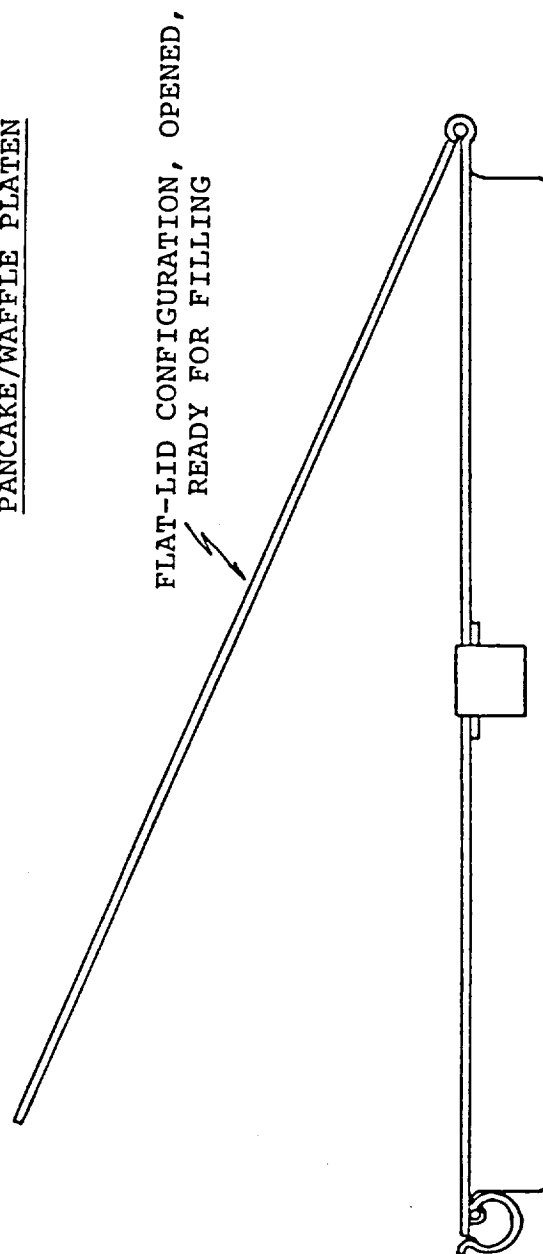
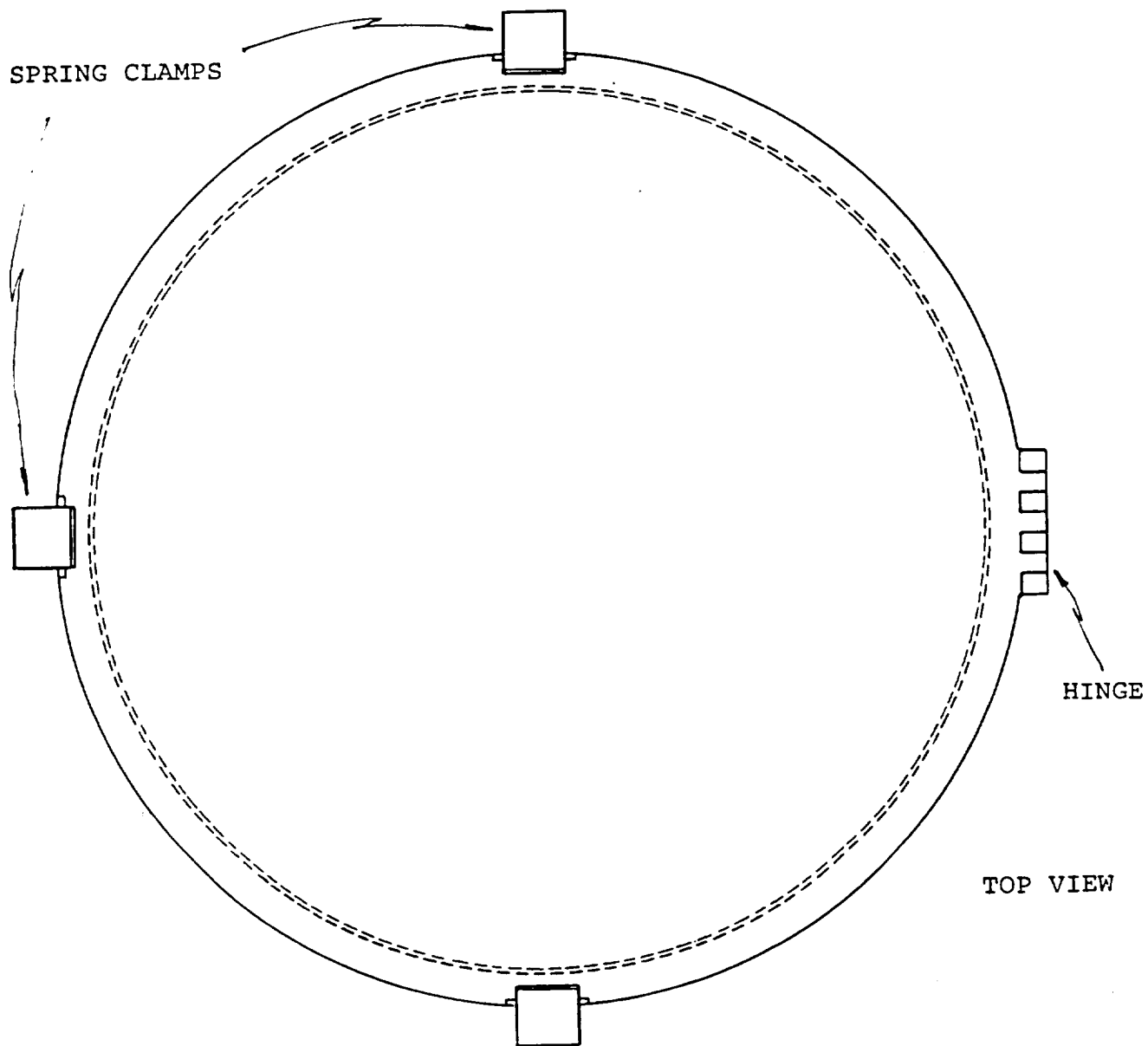
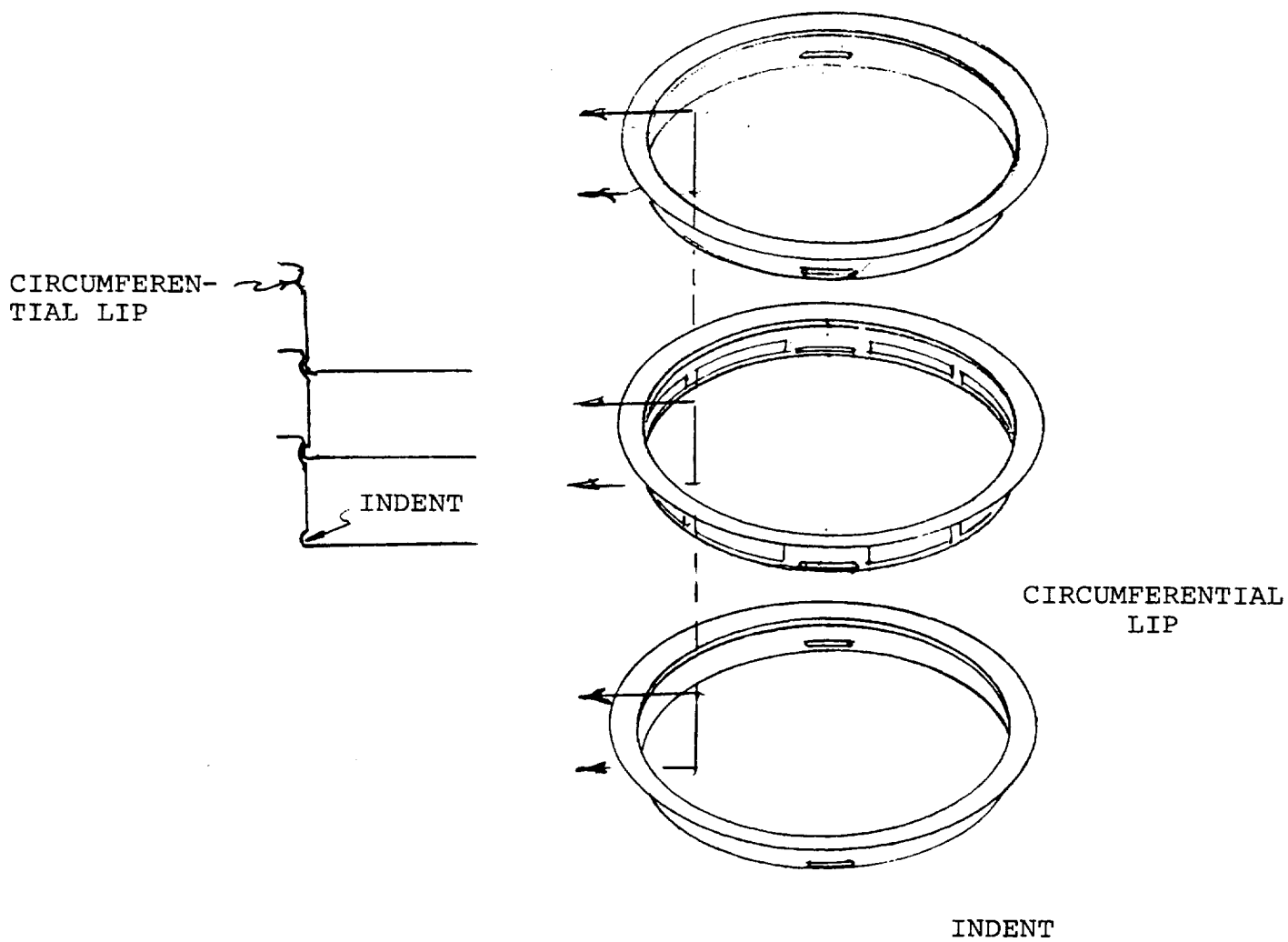


Figure 94



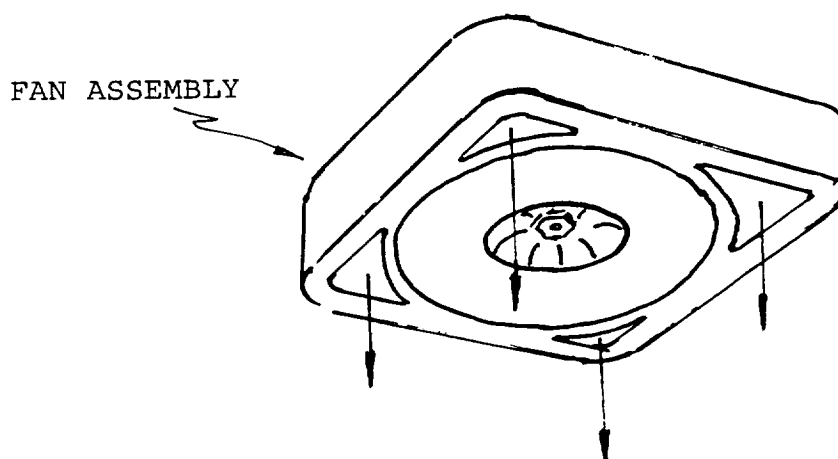
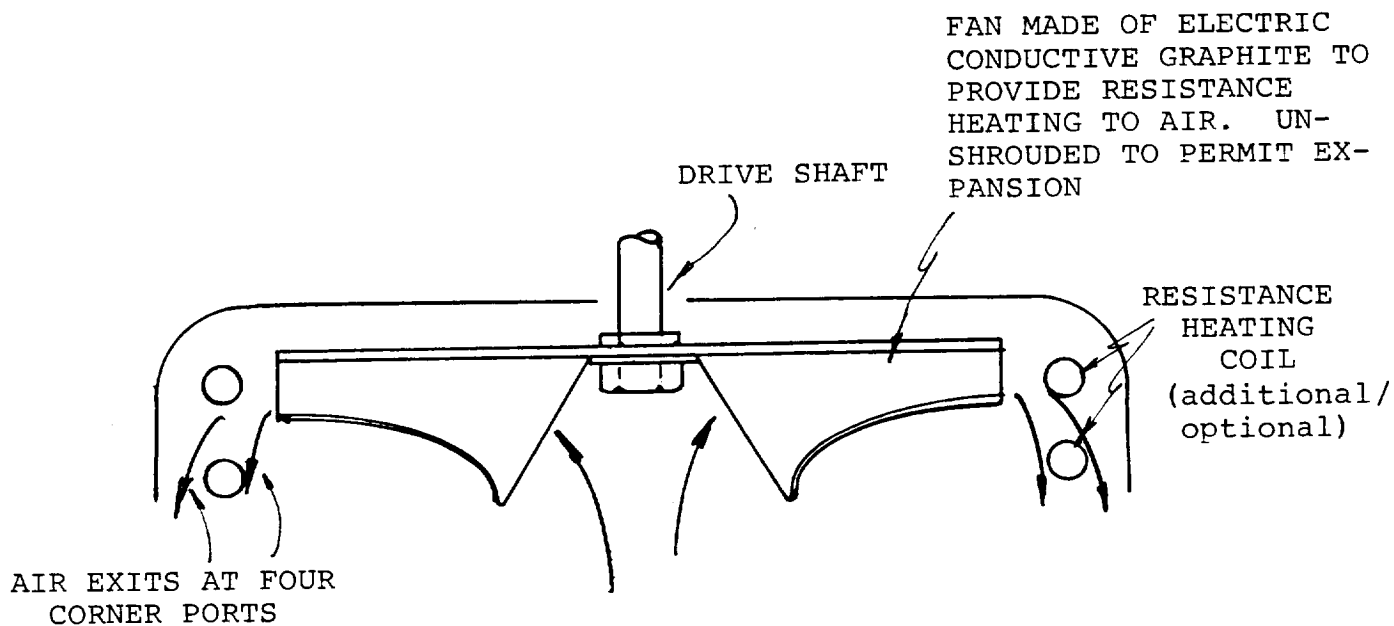
PANCAKE-WAFFLE PLATEN
FLAT-LID CONFIGURATION

Figure 95



PANCAKE PANS FOR HIGH AIR VELOCITY CONVECTION OVENS

Figure 96



FAN & HEATER ASSEMBLY

Figure 97

DETERMINATION OF THE MASS OF OBJECTS IN ZERO GRAVITY

Although all of the quantities used in preparing the products discussed in this report have been measured volumetrically, there is a further need to determine quantities by mass. The obvious approach to measuring mass is to measure the force generated by the acceleration of a body ("weighing" in earth's gravity), or, conversely, to measure the acceleration produced by applying a force to a body, both by the equation:

$$F=ma$$

where "F" is the force applied to a body, "m" is the mass of the body, and "a" is the acceleration of the body resulting from that force.

Unfortunately, the application of this equation to food products in zero-gravity is much more complex than simply weighing on earth. Practical considerations include generating and measuring the necessary forces and accelerations needed for a wide range of products, accurate computation of mass, based on these measurements, and the problem of including the mass of loosely packed particles in the measurement of the total mass of a sample. Additional complexities are added when microgravity is generated. The design of this unit would need to be able to measure and compensate for gravitational status.

AUTOMATION CONSIDERATIONS

There are two basic approaches to designing equipment with respect to automation. In the first case, humans perform all of the necessary functions using existing equipment. In the second approach, the equipment is designed specifically for an automated process. Examples include the manufacture of automobiles. In the early days, each car was assembled in its own location. Parts were carried to them, and standard tools and hand assembly techniques were used. Today, each unit operation is performed by specially designed robots at given station, and the cars are transported from one station to the next by conveyor belts with no human intervention.

Most applications, however, contain a combination of manual and automated functions. In designing systems for processing and preparing food in the GELSS environment, it is important to define the optimum level of automation, i.e. to partition tasks between machines and humans for each step in the process.

The approach FASI has taken to design its equipment is (1) to define the entire process in terms of a flow diagram. There are two areas of concern, within unit operations and between unit operations. (2) to thoroughly define the relevant parameters for each task. (3) to investigate various approaches to achieving the desired results for each stage. Each approach is evaluated first on the quality of its result, then on its applicability to the CELSS environment, and finally for its optimum level of automation.

The resulting subsystem may be a commercially available device modified for the particular requirements of GELSS, or a totally new design. Much of the existing equipment is already computer controlled, so some of the modifications may include rewriting parts of the internal control program to fit the application, changing the operator interface to fit the operator, and interfacing the device to the rest of the system to provide for integrated operations.

ALLOCATION OF TASKS

Some of the decision parameters involved in partitioning tasks between humans and machines are size, weight, and energy requirements; level of operator sophistication required; batch size and frequency of processing; time requirements; and accuracy and repeatability requirements.

Also, tasks should be allocated by suitability and ease of performance. Humans are particularly adept at pattern recognition, manual dexterity, and judgement, whereas machines (computers) excel at monitoring, control, and sequencing functions.

AUTOMATED SYSTEMS

While automation has its obvious advantages, its disadvantages also need to be taken into consideration. While automated processes can often save space, since they don't require space for humans to interact with the processes, human intervention is usually limited, often due to inaccessibility of product, and there is an inability to make minor modifications or corrections to the process.

Automated systems usually weigh more and use more energy. They are inherently more complex, leading to lower reliability and more frequent and involved maintenance and repair. Also, standard material handling techniques such as conveyor belts, gravity feed, air classification, and standard robotic pick-and-place techniques are not applicable in a zero gravity environment.

MANUAL SYSTEMS

Manual systems also have their advantages and disadvantages. A manual system is inherently simpler, and from a weight/cube point of view, manual labor is "free" in that the astronauts are available and their energy and space requirements are already being provided. On the other hand, many of the tasks to be performed are boring, time consuming, or time critical. Also, manual systems often introduce an unacceptable element of inconsistency.

APPLICATIONS

Applications of computers in the automation of food production aboard a spacecraft fall into four categories: Material handling, inventory control and menu planning, process control, and operator interface.

MATERIAL HANDLING

Material handling applies between and within unit operations. Material must be transported from storage bins to unit operations, between unit operations, and back to bins or to the table. In zero gravity conditions, closed containers and aspirators must be used in place of the more familiar transport mechanisms.

This is the area that seems to offer the fewest advantages for automation. Although some processes lend themselves to automated material handling (such as converting wheat to flour which can be a continuous process starting with aspirating the wheat heads from its bin, and ending with aspirating flour into its bin), most require manual handling between the process steps.

INVENTORY CONTROL AND MENU PLANNING

It might be possible to plan the menus for an extended space flight in advance. However, there are several pitfalls to this approach. First, even a menu that repeats itself every three weeks would become boring and predictable over an extended mission. Using an onboard computer, it would be possible to dynamically generate a quasi-random menu which would include a pleasant element of unpredictability while maintaining variety and balanced nutrition.

More important is the possibility of problems in crop production which result in uneven availability of ingredients. By keeping track of the amount of ingredients in the storage bins, and with additional input as to the condition of crops to be harvested in the near future, menus could be generated which would take into account existing as well as expected ingredient availability, again attempting to maintain variety and balance. Then, instructions could be given to the crew to modify future planting amounts to bring the system back into balance.

The possibility also exists for the crew to make "requests" of the menu generator to prepare a favorite food more often, or a specific meal at a given time. A menu could be generated to honor those requests subject to ingredient availability and nutritional balance.

PROCESS CONTROL

Process control includes sequencing and control of unit operations, control of multifunctional devices, automatic operation scheduling, and environmental monitoring and control.

Control of unit functions entails monitoring the relevant parameters (such as time, moisture content, temperature, volume, etc.) and controlling the appropriate variables (such as actuators, air flow, heating elements, etc.) to effect the desired results. An example would be maintaining optimum cooking efficiency in a microwave steamer by monitoring the steam pressure and switching the magnetrons on and off. Ongoing batch processes such as the fermentation of vinegar and lactic acid

need to be continuously monitored and controlled.

An example of the sequencing of unit operations is ordering and differentially timing the stages of the breadmaking machine to produce pizza dough, pretzel dough, or bread.

An example of controlling a multifunction device would be monitoring the moisture content in the dryer, then switching to the threshing function in the case of wheat or soybeans; stopping and signalling the operator, in the case of clothes drying; or stopping and enabling the appropriate aspirator, in the case of biomass drying.

On a larger scale, some events need to be scheduled over periods of 24 hours or longer. These include automatically turning on the self-cleaning oven once per week during a period of minimum power usage, and signalling an operator to begin the flour production process in time to provide flour for the next meal.

It is also desirable to monitor such parameters as vacuum, temperature, and humidity in the storage bins, for example, and to alert an operator if they go out of limit.

OPERATOR INTERFACE

A critical element in the efficiency of the entire operation is the way the system and the operator relate to each other. It is assumed that the astronaut has minimal expertise in the various food-related functions he/she will be called upon to perform. Since some of these functions are complex and somewhat critical, it is important that the interface between human and machine simplify the user's actions necessary to control complex operations, while at the same time guiding and protecting him/her throughout the process.

For example, in food preparation, the user should only have to specify the nature of the food to be prepared, and the devices should contain their own programs to carry out the proper operations in the proper sequence. "Smart" power packs could be designed to take instructions from the devices they are powering, so that there is no need for the operator to punch in speed or timing information at each step.

The system could also provide interactive step-by-step instructions to the user, while timing overlapping operations and notifying the operator what to do next and when. The operator would confirm successful completion via a computer keyboard before the system would continue. It could also be programmed to provide answers to a limited set of questions, and to give instructions to compensate for problems which might arise while preparing food.

It also has the potential for feedback. It could generate a questionnaire about the last meal with such questions as "Were the french fries (a) too well done (b) not done well enough (c) just right?" It could then use the answers to adjust cooking parameters for the next meal.

CONCLUSIONS

Rather than a completely automated robotics system, FASI envisions a combination of manual and automated operations, the mix at each station optimized for the particular function to be performed at that station in the context of the overall system operation.

Because of the diversity in processing operations of food related activities, it appears that the best way to limit human involvement might be to design individual "pushbutton processes", each minimizing the need to change parts and manually clean up. This would be realized utilizing manual operations which require attention blocks of five minutes or less, and significant computer assistance.

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this investigation, a majority of the operational requirements for food processing in a CELSS under weightless conditions can be met by commercially available equipment adapted for zero-gravity. In most cases, this amounts to relatively minor modifications, such as addition of extra housings and an aspiration plenum to provide an air flow to ensure that materials/products go where they are supposed to and not into the cabin atmosphere. In some cases, more substantive changes are needed; however, there is an extremely broad spectrum of equipment available, and if an approach more commonly used in 1-G appears unsuited to weightless conditions, the project team has, in most cases been able to identify another unit that would be more appropriate.

A number of concept designs have been proposed to accomplish those unit operations where no suitable existing is available. For the most part these have involved systems related to materials handling, more particularly, to maintain control of particles and fluids as contrasted to process-related systems. Specific examples include measurement and transfer of dry particulate materials, classification/separation of particulate materials, mixing of solids and liquids, and systems, such as breadmakers, which integrate these types of operations. Other concept designs, such as the pancake-cooker and the oven-steamer have been proposed as extensions of commercially existing equipment which would improve the product diversification for astronaut crews, and may find valuable applications in food preparation and processing here on earth.

While it appears entirely feasible to preprepare, process and prepare food in sufficient quantity and quality to support extended space missions, many challenges remain, particularly in the area of process development. Specific processes that merit investigation include: a simple, low water usage process for obtaining gluten from wheat; a simple, low heat method for inactivating lipoxxygenase and removing stachyose and raffinose from soybeans without reducing soy protein solubility; fermentation techniques/systems that can avoid or limit foam production; and

a simple, low temperature/low pressure method of refining and hydrogenating vegetable oils. In terms of prioritization, from a foods standpoint, it would appear that they are in approximately the proper order as listed. FASI intends to submit an SBIR proposal on obtaining gluten from wheat. Another of these areas, soy processing may be covered under Phase III funding FASI has been awarded by the North Central Soybean Research Program.

FASI intends to file patent applications for perhaps 10 or 12 of the concept designs developed out of this Phase II program. Two companies have indicated potential interest in licensing agreements based on successful filing.

Because of the small crew size, and the desire to plant and harvest on a daily basis, it would appear that opportunities to make effective and efficient use of robotics/automation are limited. These approaches are best used in circumstances involving repetitive tasks or large volumes, neither of which exist in the given scenario. The approach seeming most effective in reducing personnel involvement is the linking of operations where possible so that material flows from one operation to another without intervention. The second approach is to simplify operations, especially in terms of set-up, use, and cleanup. The third is to anticipate and build practical solutions into concept designs from the very start, particularly for problems such as particle control. The fourth approach is to design facilities to have built-in convenience and avoid clutter which creates problems and inefficiency. Specific examples might include the design and location of power-paks, and the design of equipment where possible for collapsibility and stowage. A fifth approach is to select/design equipment with an emphasis on versatility to minimize the amount of equipment needed. In carrying out this Phase II program, the FASI project team has made every effort to utilize all five of these approaches as effectively and practically as possible.

APPENDIX A

EVALUATION OF THE AMERICAN HARVEST JETSTREAM OVEN USING CELSS-AVAILABLE INGREDIENTS

<u>PRODUCT</u>	<u>Page</u>
Fried Potato	A- 1
Pizza	A- 2
Casserole	A- 4
Pancakes	A- 6
Wheat Gluten Meatballs	A- 7
Coffee made from Wheatberries - I	A-10
Coffee made from Wheatberries - II	A-14
Coffee made from Wheatberries - III	A-15
Coffee made from a Wheat/Soy blend	A-19
Summary of Jetstream Oven Trials	A-20

CONTRACT NAS2 - 13404
CELSS FOOD SYSTEM

4 FEBRUARY 1993

EXPERIMENT WITH CYCLONE OVEN: # I.

I. OBJECTIVE:

The objective was initial familiarization with use of this high velocity hot air oven - Jetstream model from American Harvest, Chaska, Minnesota.

II. APPROACH:

The approach was to simply follow the manufacturer's directions to prepare a typical food product. Ranch style potatoes were selected primarily since the white potato is one of the CELSS crops. The preparation and heating followed directions given in the American Harvest guide, page 32 for Jetstream potatoes.

III. RESULTS AND COMMENTS:

A. After 15 minutes potatoes had good flavor but needed more cooking time. After 19 minutes, potatoes were uniformly soft and had a deep brown color. Flavor was good reminiscent of baked potato. Slight odor during cooking was also that of baked potato. Noise of unit during cooking was not irritating.

B. Comments relative to oven's use in CELSS (zero gravity):

1. Need to watch endpoint carefully. Can, at least for potatoes, overcook/bake easily. Not surprising - heat transfer rate is high.
2. Need a glove box in which to wash potatoes. (May be that hydroponic potatoes can be harvested clean enough to skip washing.)
3. Cutting longitudinally into quarters can be done by hand against a solid surface; left skins on.
4. Coated with melted oleo - brush would work well but is difficult to clean. I used a paper towel rolled so that one end resembled a brush, used it that way and then discarded it.

C. Overall assessment is that oven cooks well and uniformly; product remains internally moist. Oven is fast. Further testing with CELSS ingredients, their commercially available equals, and CELSS products is warranted.

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CELSS FOOD SYSTEM

EXPERIMENT WITH CYCLONE OVEN: # II

I. OBJECTIVES.

1. Establish/evaluate capabilities of American Harvest (A/H) cyclone oven.
2. Determine if a pizza-like product is feasible using current CELSS ingredients/interim products.

II. PROCEDURE.

1. Used oven's bottom rack in upper position and hold-down rack at level 3 (it touched top of product in the #3 position). Preheated oven at 400f for 1½ minutes.
2. Pizza ingredients from the bottom to the top were:
 - a. Store-bought frozen pizza shell, used a ¼ slice of a 12 inch diameter shell. After 5 minutes on counter top, shell felt spongy; i. e., semi-thawed.
 - b. An approximately 1/16 - 1/8 inch layer of soft tofu that had been whipped with a fork into a slurry. Spread and smoothed with a soup spoon.
 - c. Strips of "tofu mozzarella cheese alternative" spread over 50 - 60% of surface. Strips were ¼ inch wide, 2 -2½ inches long, and 1/16 - 1/8 inch thick.
 - d. Chopped soy bean sprouts - approximately ¼ of a measuring cupful.
 - e. Slices of "tofu pups"; 1/8th inch thick slices of tofu based frankfurter analog. used 8 - 10 slices/disks.
 - f. Nothing else.
3. Put the slice on the center of a rimless 12 inch diameter circular pizza sheet.
 - a. Turned air on low at 375F for 30 - 45 seconds. Nothing blew off so I turned air on high and temperature to 400F.
 - b. Heated with inspection (stop air and lift cover; visual judgment) at 3, 3½, and 4 minutes. At 5 minutes, decided product was done. "Sauce" (cheese and tofu) was bubbling; surface and pizza shell were slightly brown.
 - c. At start of high air velocity, some ingredients moved slightly, but hold-down rack prevented any loss. I would judge that after 1 minute, ingredients were "set".

III. RESULTS.

1. Product was done/cooked - shell was crisp, topping was hot and a pleasant brown on peaks and raised areas.
2. Flavor was mild and bland; no objectionable flavor notes. Flavor from "pups" helped give some zip.
 - a. Salt, vinegar, pepper would help.
 - b. Found myself returning for repeated samples. Wife also found product acceptable yet bland.
3. This is a good one dish meal - important in space.

IV. CONCLUSIONS.

1. A pizza-like product is feasible using CELSS ingredients. Basically, soft tofu is substituted for the U.S. traditional tomato sauce.
2. The A/H cyclone oven works well in preparing pizza - 5 minutes; no real clean-up needed.
3. Could use flavor enhancement/constituents; will try peppered sweet potatoes, etc.

4. Good one dish meal - simple, comprehensive nutritionally.

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CELSS FOD SYSTEM

EXPERIMENT WITH CYCLONE OVEN: # III.

I. OBJECTIVE:

Using CELSS ingredients, determine whether the cyclone oven can be used in the preparation of a casserole dish (i.e., a typical one dish meal using the potatoes). The anticipated advantages are good flavored sweet and white potatoes and a surface browning.

II. PROCEDURE:

1. Sliced sweet potato and white potato into $\frac{1}{2}$ " (1.3 cm) thick diagonal pieces. Coated with oleo and heated in cyclone oven for 4 minutes at 400 F (204C) at high air flow. Potatoes were slightly brown and $\frac{3}{4}$ done.

2. Mixed into a $4\frac{1}{2}$ " (11.4 cm) diameter Pyrex dish $8\frac{1}{4}$ " (20.6 cm) thick slices of Tofu Pup franks; $\frac{1}{2}$ of a $3\frac{1}{2}$ " (8.9 cm) diameter, $\frac{1}{2}$ " (1.3 cm) thick tempeh burger cut into $\frac{1}{2}$ " (1.3 cm) cubes; and enough soft Tofu to cover. This material became one inch (2.54 cm) thickness in the dish. Microwaved for 2 minutes at full power (sort of a preheat).

3. Layered sweet and white potato slices on top of product in the dish, covered with more soft tofu to a total thickness of 2" (5 cm)

4. Topped with slices of soy cheese analog and cyclone ovened for about 7 minutes using the bottom oven tray (no rack) at 400F (204C) and low air velocity (high air velocity caused dish to start moving around the tray perimeter in a clockwise direction).

III. RESULTS:

1. Dish, when done, had a nice browned surface - looked good.

2. Product tasted relatively bland. The pre-roasting of the potatoes provided a mild baked/roast potato flavor; was difficult to differentiate between the white potato and sweet potato used. (I did not have the best sweet potato.) The sliced Tofu Pups also provided some flavor. There were no objectionable flavor notes. Small addition of salt helped acceptance significantly. Perhaps I should have added some into the mix. Overall, quite acceptable.

3.a. The potatoes were firm and barely done - need to pre-cook for 5 - 6 minutes instead of four.

b. The soft tofu in the final product appeared curdled and there was some free liquid. This presented a less than optimum appearance. However, flavor was not affected; i.e., not different from non-separated tofu. Perhaps the use of a blender and/or firm tofu would present a better appearance.

c. Would also preheat pups, burger bits, and tofu mixture for 3 minutes in lieu of 2 in a microwave. Would help with final temperature.

IV. CONCLUSION:

Procedure works. The use of microwaves for internal and/or preheating of a thick (2"/5 cm) casserole and cyclone oven for flavor and color development in addition to heating of constituents as a final dish is a useful procedure. Steps are straightforward and a one dish meals results. Photos were taken.

OPTION: Try mixing entire dish at one time instead of the two - step approach tried this time. Then heat in a microwave oven for 5 - 6 minutes and 5 - 8 minutes in the cyclone oven. Use microwave to provide internal heating and

then cook and brown with the cyclone. Still need to precook the potatoes and for a little longer time for flavor development.

CONTRACT NAS2 - 13404
CELSS FOOD SYSTEM

9 April 1993

PANCAKES IN THE AMERICAN HARVEST JETSTREAM OVEN

I. OBJECTIVE:

By the use of a thinner hollow platen or covered dish - 1.3 cm or $\frac{1}{2}$ " inner height - determine whether pancake can be prepared in the American Harvest oven without the need for flipping or in-process inversion of the platen, i.e., will the final product be cooked and adequately browned on top and bottom surfaces?

II. PROCEDURE:

1. For the "bottom" platen used a commercially available cover designed to cover burners on an electric kitchen range. This cover was 8.5" (21.6 cm) in diameter, $\frac{1}{2}$ " (1.3 cm) deep with the circumferential side at right angles to the flat surface. The "top" was a flat disk about 9.5" (24.1 cm) in diameter cut from a steel cookie sheet. After loading, the top was kept in place by a binder clip and two large, (8 cm) deep, paper clips.

2. Prepared a standard pancake batter using the same Fannie Farmer Boston Cooking School Cook Book recipe as before. Filled the bottom platen to a thickness of $\frac{1}{8}$ - $\frac{3}{16}$ " (0.32 - 0.48 cm), assembled the unit and cooked in the A/H oven using the lower rack in it's upper position and the hold down rack to prevent platen movement. Made three runs:

a. Batter was on the thick side, so I had to spread the batter with a spoon. Preheated oven for 2 minutes at 204C and cooked the unit for 5 minutes at 204C (400F) and high fan speed. Calculated volume of batter is 146 cc.

b. Diluted the batter so it was flowable/easily pourable - repeated run as in "a." above. Did not regrease pan. Did spread batter slightly.

c. Poured some batter (75 cc or so) onto center of bottom, did not spread; ran 6 minutes at 204C (400F).

III. RESULTS:

1. Run #1 - Top very nicely and evenly browned. Pancake occupied 90% of internal volume of platen cooker. Bottom was browned on edges and an acceptable yellow in the center. Pancake was uniformly cooked - even in the center - the last place to be cooked. Platen idea works. Needed oven mitts to unload from oven; however, platen was cool enough to handle in 4 - 5 minutes at room temperature; and clean.

2. Run #2 - Not as good as the first one. Could have used greater fill and needed to grease again - by wiping. Did go 6 minutes. Not as brown but was uniformly cooked.

3. Run #3 - Did cook - light brown. had gone 6 minutes at 400F (204). done uniformly.

4. Overall:

Platen works - need to standardize fill weight/volume and to use a release agent. Light weight platen is easy to handle. No interim inverting required.

RAL

**CONTRACT NAS2 - 13404
CELSS FOOD SYSTEM**

4 APRIL 1993

EVALUATION/FAMILIARIZATION WITH GLUTEN MEAT ANALOG (WHEAT BALLS)

I. OBJECTIVES:

Objectives were familiarization with a commercially available "wheat ball" mix (Knox Mountain Farm) (gluten, crushed wheat berries, spices) and determining likelihood of its adaptability to CELSS. Primarily, adaptation would involve a substitute for a water boiling step and assessing the applicability of the American Harvest Jetstream oven.

II. PROCEDURE:

Basically followed the instructions on the package with some heating and cooking variations.

1. Added 1 oz. (29.6 cc) soy sauce to 7 oz. (207 cc) water. Added this to the 8.5 Oz. (240 gms) of dry "wheat ball" mix. Kneaded by hand until uniform in texture and appearance. Rolled into 21 wheat balls.

2. Then divided and treated the wheat balls as follows:

a. 4 - in a small tray with small amount of soy-water mixture in the bottom; covered with aluminum foil and heated in the A/H oven 12 minutes at 400F (204C) using high fan speed.

b. 4 - moistened with tap water and wrapped in aluminum foil. Heated in A/H oven 12 minutes at 204C and high fan speed.

c. 13 - boiled for 25 minutes in a broth of 1/4 cup soy sauce in 8 cups of water (60 cc soy in 1894 cc water).

3. Cooked/baked the wheat balls as follows:

a. Both the tray and foil wrapped wheat balls in the A/H oven 8 minutes at 375F (190C) and high fan speed.

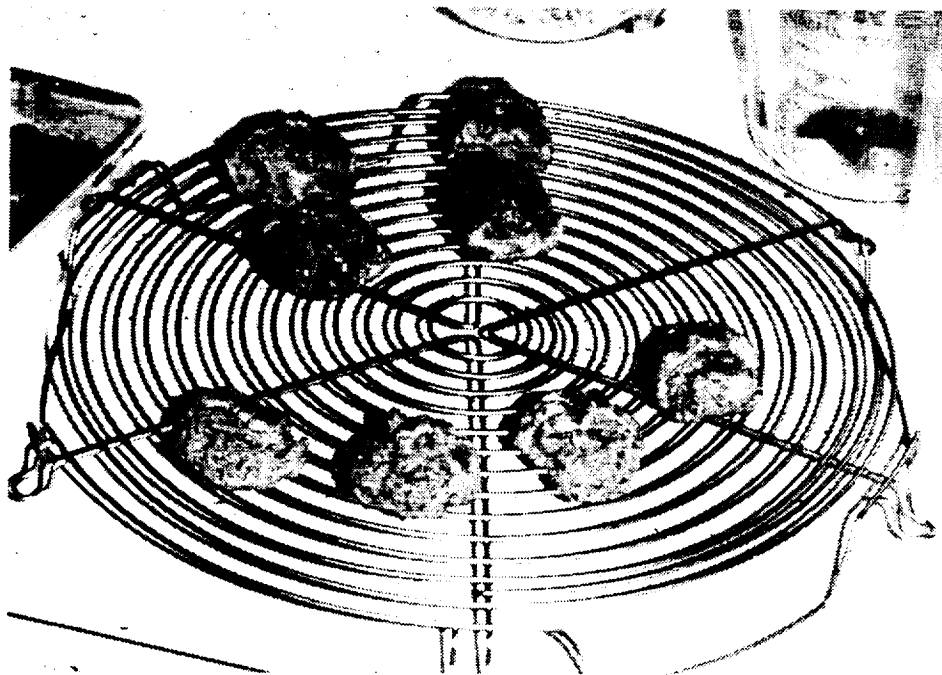
b. The wheat balls that had been boiled for 25 minutes were divided into two groups: one group was baked in a shallow pan at 350F (177C) for 25 minutes in a home style GE oven per package instructions; a second group was baked in the A/H oven at 375F (190C) for 12 minutes at high fan speed.

III. RESULTS:

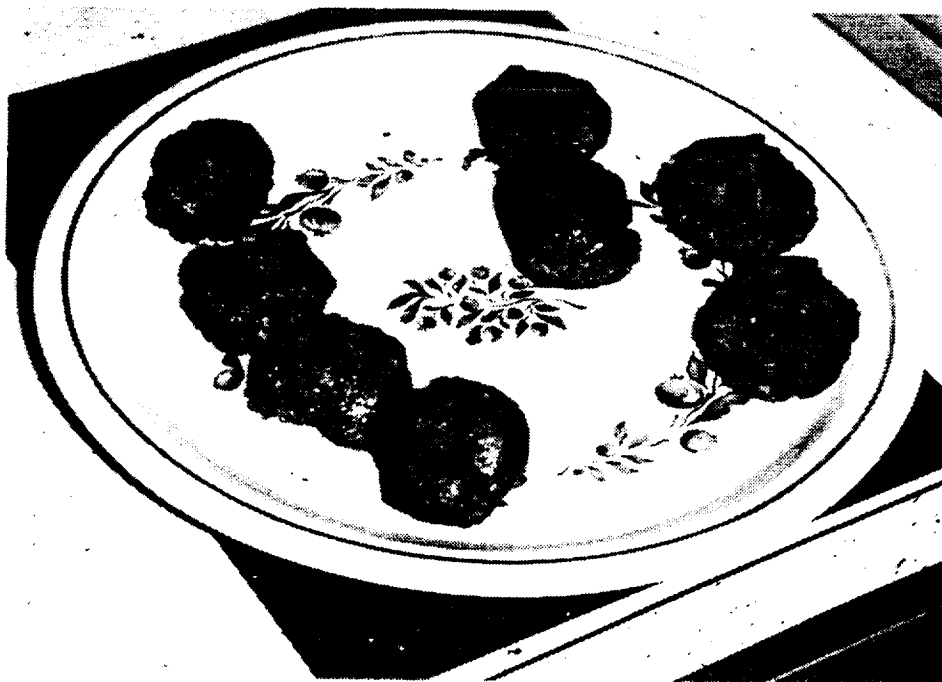
A. The wheat balls that had been "steamed" in foil and in the shallow tray, followed by A/H oven heating 8 minutes, 190C, were case hardened and a deep brown color - reminded one of a snack rather than an entree item - chewy but not gummy. They had not increased in size very much. need to repeat with more water in the tray. I thought internal texture was slightly better than those boiled in water for 25 minutes.

B. Those wheat balls that had been boiled in water for 25 minutes swelled to almost double their initial diameter. There was very little discernable difference in appearance between those baked in the A/H oven and those baked in the standard home oven. Those from A/H oven were very slightly browner/better. Those from the A/H oven had a firmer (more acceptable) interior texture; those from the standard oven were rubbery. Both had a very acceptable flavor.

RAL

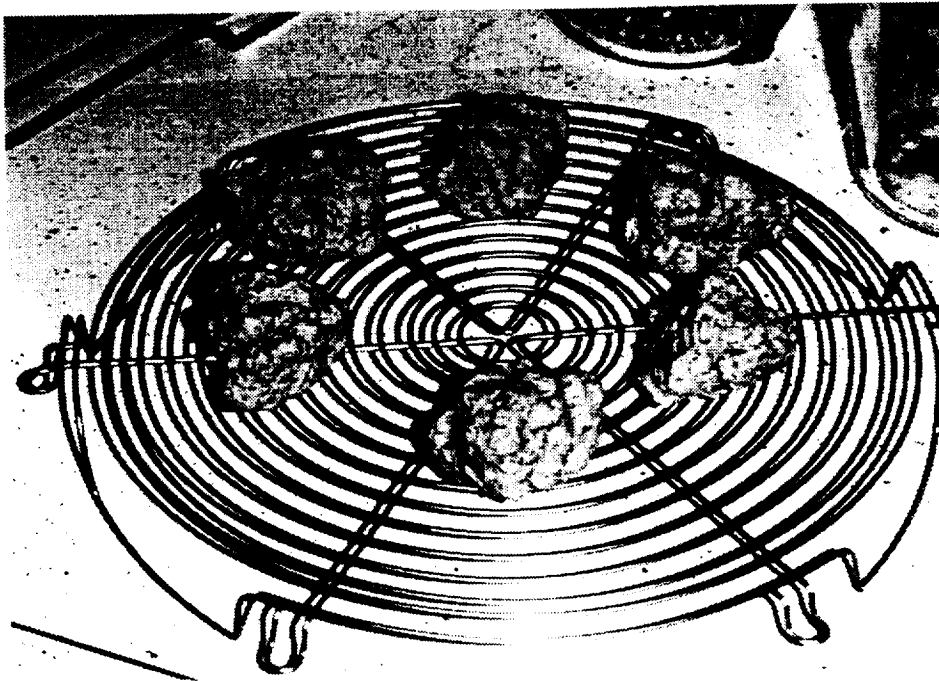


Top/square: Steamed in foil prior to baking
Bottom/row: Steamed with water in covered tray prior to baking



After baking in A/H oven 8 minutes at 375F (190C)
Left: Preheated in aluminum foil overwrap.
Right: Preheated in covered aluminum tray with small amount of water.

WHEAT BALL PREPARATION (GLUTEN MEAT ANALOG) 4 APRIL 1993



Wheat balls after boiling for 25 minutes and prior to oven baking



Left: Wheat balls baked in A/H oven - 12 minutes at 375F (190C)
Right: Wheat balls baked GE home oven - 25 minutes at 350F (177C)

CONTRACT NAS2 - 13404
CELSS FOOD SYSTEM

30 MARCH 1993

EXPERIMENT: WHEAT BERRY "COFFEE".

I. OBJECTIVE:

The objective is to determine whether a substitute hot drink (ersatz coffee or tea) can be made using the American Harvest Jetstream Oven to roast wheat berries; followed by grinding and hot water extraction.

II. PROCEDURE:

A. A 3/4 measuring cupful (ca 180 cc) of whole wheat berries was put into a small basket made of aluminum window screening measuring 1/2" (1.3 cm) high and 4 3/4" (12 cm) square.

B. These berries were roasted in the A/H oven at 400F (204C) for 4 minutes at low speed and 6 minutes at high fan speed. Used the lower rack in it's upper position and the hold down rack to prevent levitation or circling. The roasted berries were then cooled at room temperature for 30 minutes before grinding.

C. The berries were ground in a small electric powered coffee mill to a fine to medium powder. Used a one cup Melitta " filter cone" coffee maker catching the exudate in a graduated glass. Tried to get a final volume of one cup to simulate conventional coffee preparation. Used boiling water.

1. Ran 1 measure (29.6 cc) of ground berries first. Measure is a standard 1 tablespoon coffee measure.

2. Ran two measures when it became obvious that extract would be too weak.

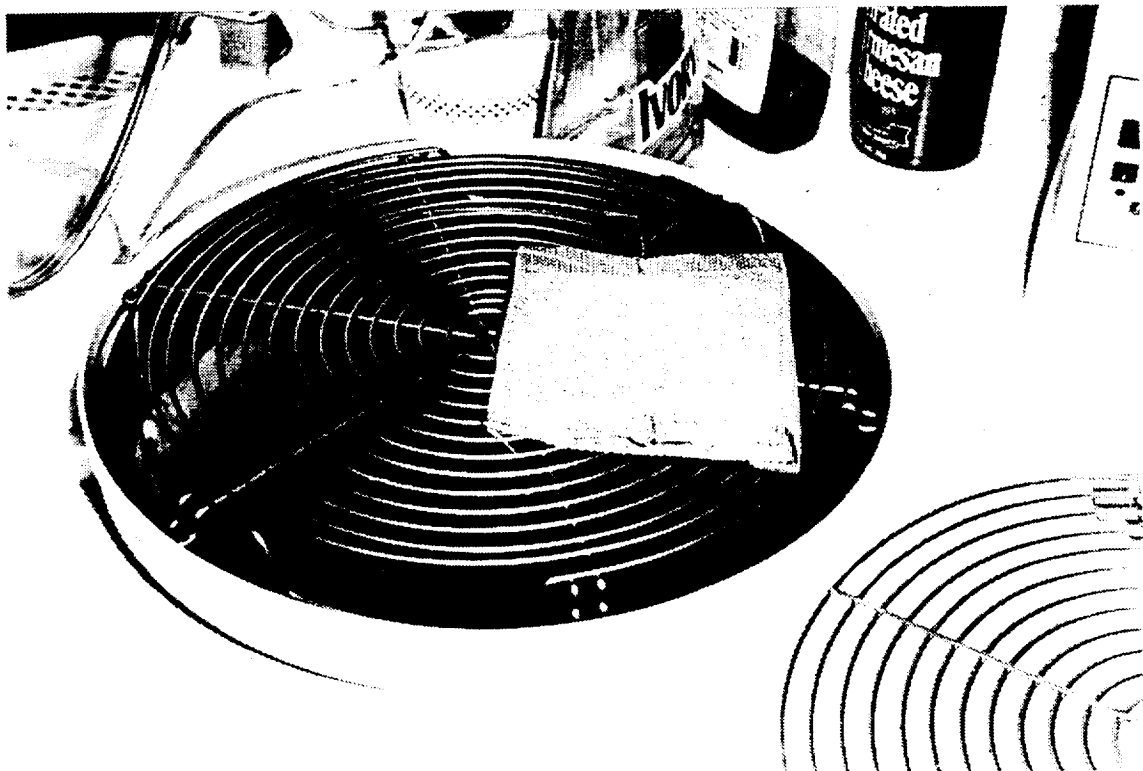
III. RESULTS:

A. First trial (one measure) resulted in a very weak extract. Filtration rate was very slow in spite of periodic stirring of the mixture in the cone. Final yield was 3.5 fl. oz. (104 cc). Estimate that 1.5 oz. (45 cc) were left in the cone. Product was yellow-brown and slightly hazy. Taste was unique in that I could not compare it with any other item I have tasted. Taste was mild with no objectionable flavor notes; there was a slight bitterness. No hint of coffee or tea. Did leave a slight bitter/dry residual mouth-feel a la tea.

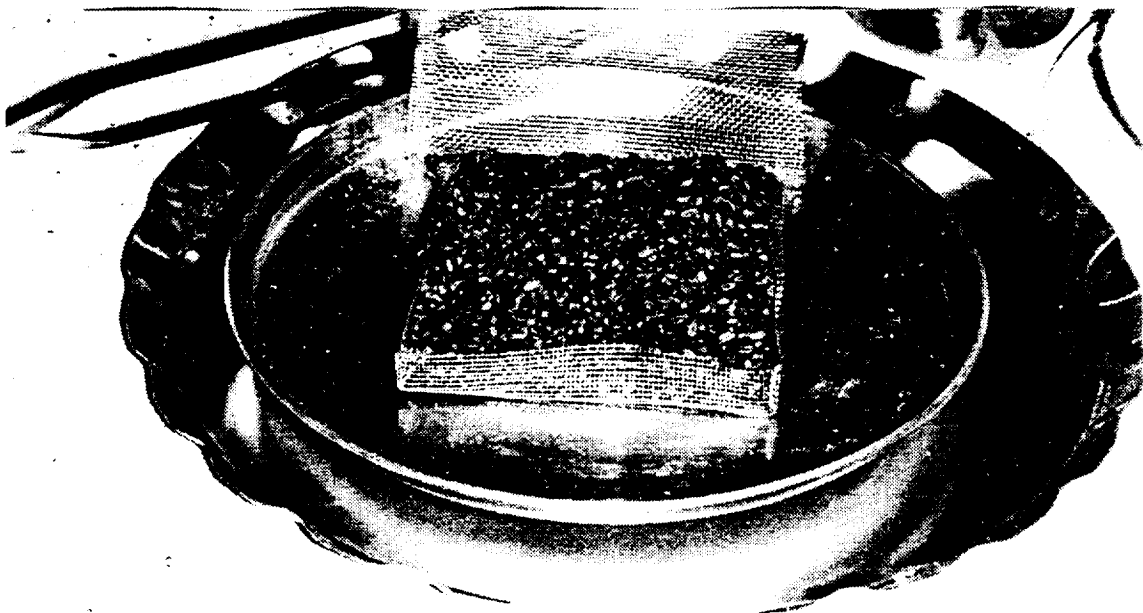
B. The second trial with 2 coffee measures resulted in a darker filtrate - equal to iced tea in color and intensity.

C. Overall, taste is unique but I can visualize that one could get used to it; it is not objectionable. The flavor and color intensities were not strong enough; need to try a longer roast (30 minutes) and to supplement gravity during filtration by pressing the filled filter against the cone with the round side of a spoon. Will use cheese cloth in cone prior to putting in the filter paper to provide strength during pressing.

RAL



Wheat berries in window screen basket prior to roasting in American Harvest oven



Wheat berries after roasting for 10 minutes at 204C and high fan speed



Ground roasted wheat berries

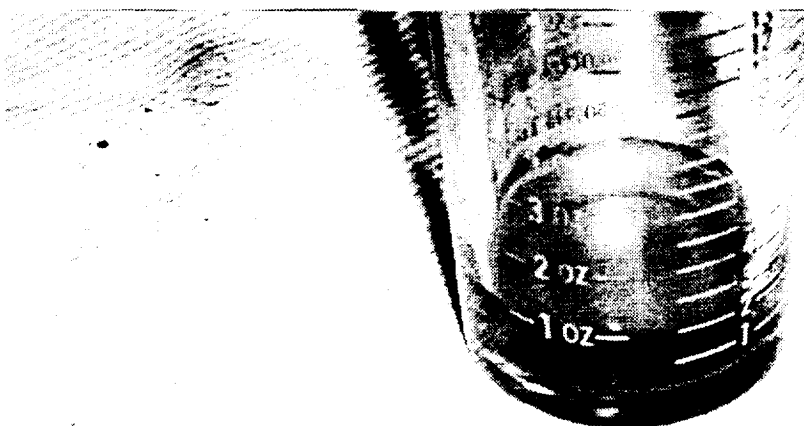


Coffee making/extraction procedure using ground wheat berries

EXPERIMENT ON WHEAT BERRY "COFFEE" 30 MARCH 1993



"Coffee" extracted from 29.6 gms (1 ounce) of ground wheat berries per cup.



"Coffee" extracted from 59.2 gms (2 ounces) ground wheat berries per cup.

ORIGINAL PAGE IS
OF POOR QUALITY

CONTRACT NAS2 - 13404
CELSS FOOD SYSTEM

2 APRIL 1993

EXPERIMENT: SECOND TRIALS: WHEAT BERRY COFFEE

I. OBJECTIVE:

A. The objective is the use of the A/H oven to roast wheat berries for subsequent use for making a hot coffee simulating drink.

B. Reference is made to initial trials documented in experiment write-up, subject: Wheat Berry "Coffee", dated 30 March 1993.

II. PROCEDURE:

A. Background: Initial trials had indicated that a ten minute roast was inadequate; drink/extract was too weak. Therefore, it was decided to try a thirty minute roast next and if too long, cut back on the following run to 20 minutes. Also decided that gravity filtration was too slow and inappropriate for zero gravity; therefore, planned to squeeze water- ground berry mixture to speed up extraction/leaching.

B. Details of procedure:

1. Roasted 180 cc of berries in the wire basket used for the first trial at 204C for thirty minutes at high fan speed.

2. Ground the berries to a uniform fairly fine powder in the small electric coffee mill.

3. Prepared the Melitta cone by first lining it with cheese cloth, then with filter paper, and finally putting in the cone, two measures of the ground berries. Poured hot water onto the powder in the cone.

4. Allowed approximately 2/3's of the filtrate to accumulate freely; squeezed the final third out using the cheese cloth as a bag and pushing the round side of a spoon against the bag and to the cone wall. In this way, it was possible to handle the hot bag. Total volume extracted was 3.5 fl. oz. (ca 100 cc.).

III. RESULTS:

1. Extract ("coffee") was dark - equivalent to strong cup of conventional coffee; i.e., appearance was good.

2. Taste was strong had a suggestion of coffee; slightly bitter; no other objectionable flavor notes. It has it's own characteristic taste; question is whether this taste can be acquired and accepted. Except for the bitterness, I personally feel it can.

3. Added a "pinch" of sugar to 60 cc. of filtrate/coffee - this did offset the bitterness to some extent.

4. Overall, the trials are promising enough to justify continuing with them. Next, will try:

* A 20 minute roast to see if bitterness is reduced; will try a syrup in lieu of sugar.

* Since bitterness is one of the primary tastes, it may be difficult to overcome; may try marinating with mild acetic acid (vinegar) - marinate, dry, roast. Also a dab of soy sauce may help.

* Will try addition of soy milk.

RAL

CONTRACT NAS2 - 13404
CELSS FOOD SYSTEM

17 MAY 1933

EXPERIMENT: WHEAT BERRY COFFEE: THIRD SERIES.

I. OBJECTIVE:

The 30 minute roast of wheat berries had resulted in a dark, flavorful extract or ersatz coffee. However, the taste had a bitter note that would be desirable to eliminate or at least minimize. Therefore, one objective was to determine if a 20 minute roast would yield enough flavor but not as much of a bitter taste.

It had been noted that gluten based "wheat balls" used ground wheat berries, were processed with soy sauce in two of the preparation steps, and had no residual bitter flavor. Therefore, a second objective was to determine whether soy sauce or vinegar (also an ingredient apt to be available from CELSS) solutions have any de-bittering effect. Will use either the 20 minute or 30 minute as established during the first objective.

II. PROCEDURE:

1. Roasted 200 cc. of wheat berries at 205C for twenty minutes at high fan speed in the A/H oven, allowed them to cool, ground them in a small mill, made coffee using 60 cc powder and hot water to yield approximately 150 cc of extract/coffee. Made a direct comparison with extract from a 30 minute roast lot of berries.

2. Soaked two aliquots of 600 cc each of wheat berries in each of two solutions:

a. 730 cc water and 120 cc soy sauce

b. 480 cc water and 360 cc 50 grain white vinegar.

Each batch was held at 10 -15C for 14 hours, drained and dried for two hours at 58C in the A/H dehydrator. Each batch was then kept in polyethylene bags pending roasting. Based on the results of Paragraph II.1. above, roasting was performed for 30 minutes at 205C at high fan speed.

3. Prepared "coffee" from each as described above in Paragraph II.1. Made a direct comparison between the soaks and extract from plain 30 minute roast berries.

III. RESULTS:

1. Wheat berries - 20 versus 30 minute roasts.

a. The 20 minute roast had less bitterness, but also less color and flavor. The length of roast does affect yield of flavor constituents.

b. The 30 minute roast was dark and did have some bitterness.

c. Although the ideal roast time may be 25 minutes, I will go with the 30 minute roast for now. Rationale is that 30 minute roast gave more color and flavor and is a better basis for judging the effectiveness of treatments (vinegar and soy sauce soaks) for trying to reduce bitterness or eliminate it.

2. Plain wheat berries versus wheat berries soaked in vinegar. A direct comparison of freshly made extract batches was made. If one cooled, it was microwaved to bring temperature up.

The vinegar soak/roast still had some bitterness in the extract, probably equal to that in the plain roast. However, it's negative impact was offset by the presence of a new flavor - reminiscent of citrus - citric acid and slightly metallic - mild but rather nice. This new note covers up or at

least detracts from the bitterness to some degree. I could get used to the vinegar soak/roast product. The plain soak also had very little flavor other than the bitterness.

The vinegar soak/roast also resulted in a clearer, less hazy but equally intensely colored extract.

3. Plain roasted wheat berries versus soy sauce soaked and roasted wheat berries. Direct comparison again.

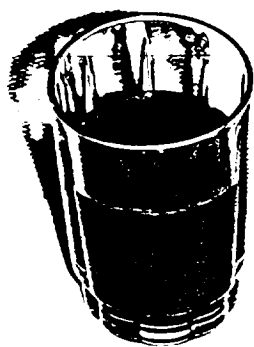
The first sip of soy soaked "coffee" brought to mind Mid-East coffee without the "chewy" texture. Bitterness is modified and is either less or masked by the effect of the treatment. It did not have the low level citric/metallic note that the vinegar soak extract had. Very dark, but not hazy or suspended matter. Tried adding a little skim milk which improved acceptability.

4. Both treatments, to me, improve the hot beverage flavor in comparison to plain roasted wheat berries. Product is becoming acceptable.

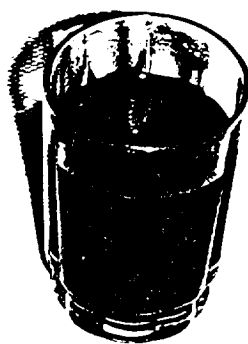
Could try combined or sequential vinegar and soy sauce soaks; could try a soy soak with shorter roast time since the soy soak extract was darker that might need be.



Procedure for making coffee using cheesecloth to allow pressing to increase yield



20 MIN. ROAST



30 MIN. ROAST



Extracts from 20 and 30 minutes roasts at 205C



Extracts from 20 and 30 minute roasts of plain wheat berries and extract from wheat berries soaked in vinegar solution prior to roasting

CONTRACT NAS2 - 13404
CELSS FOOD SYSTEM

17 MAY 1993

EXPERIMENT: "COFFEE" FROM BLEND OF ROASTED WHEAT BERRIES AND ROASTED SOY BEANS

I. OBJECTIVE:

Determine if roasted and ground soy beans alone or in a 50/50 mix with roasted and ground wheat berries can be a base for a hot beverage or "coffee".

II. PROCEDURE:

1. Roasted soy beans for 30 minutes at 205C, high fan speed, in the A/H cyclonic oven. Let them cool and ground the roasted beans to a powder in a small coffee mill.

2. Made three batches of coffee:

- a. 100% soy beans,
- b. 50/50 soy beans/plain roasted wheat berries, and
- c. 100% wheat berries.

3. Made a one person comparative taste test.

III. RESULTS:

1. Darkest was the 100% soy bean extract. Beans were almost black after roasting.

2. All three had a bitter note. Most intense with 100% soy; hardly any detectable difference between 100% and 50% soy as to bitter note. 100% wheat berries was mildest.

3. Overall, I preferred the blend but can not identify any specific reason; best is "suggestion of coffee". These tests must be considered very preliminary and crude. A qualified taste panel might reverse the above observations or might even find the bitter note not objectionable.

4. Going by memory of tests performed 24 hours earlier, I prefer the vinegar or soy sauce soaks. Would need to repeat with comparative testing before any firm conclusion can be drawn.

5. I feel confident that an acceptable hot beverage/ersatz coffee is feasible.

SUMMARY OF EXPLORATORY EXPERIMENTS

HOT BEVERAGE (A LA "COFFEE") FROM CELSS INGREDIENTS
AND
USE OF AMERICAN HARVEST CYCLONIC OVEN IN THE PROCESS

Rauno A. Lampi
18 May 1993

A. INTRODUCTION.

A series of experiments have been made using roasted wheat berries and, in one final test, roasted soy beans, to determine whether, using ingredients likely to be available in CELSS, an acceptable hot beverage; i.e., a coffee or tea substitute, is possible. The experiments have been exploratory, and further treatments and optimization of processing parameters are necessary. Results have been based on one person's tasting (a drinker of black coffee) but expert panel evaluations should be performed to confirm the findings.

B. SUMMARY OF EXPERIMENTS.

Five series of tests were made with results summarized as follows:

1. Wheat berries roasted for 10 minutes.

Roasting performed in A/H cyclonic oven at 205C; 60 cc powder with hot water to yield 150 cc extract; flavor level was inadequate; slow filtering, need external pressure for adequate extraction.

2. Wheat berries roasted for 30 minutes.

Roasting at 205C; strong flavor and color; taste had a bitter note; offset to some extent by adding sugar.

3. Wheat berries - 20 vs 30 minute roasts (to reduce bitterness).

Less color and flavor with 20 minutes; bitterness remains. Will stay with 30 minutes for subsequent tests. 25 minute roast may be good.

4. Wheat berries - vinegar soak, dry and roast at 205C

- soy sauce soak, dry and roast at 205C

(for effect on bitterness and overall flavor/acceptance).

Both extracts more acceptable than untreated control. Vinegar soak extract had a citrus/metallic note that offset some of the bitterness; soy sauce soak extract had hint of Mid-East coffee flavor that masked some bitterness. Addition of skim milk improved acceptability.

5. Wheat berry - soy bean blends

Roasted berries and beans at 205C; made 100% soy bean, 50/50 soy and wheat, and 100% wheat berry extracts for comparative evaluation. Blend was most acceptable in flavor; 100% soy beans had darkest extract and a bitterness; 100% wheat berries was mildest.

III. RESULTS AND CONCLUSION.

Some of the extracts are very close to being acceptable as is, and a taste for them could probably be acquired. The most acceptable of the variables examined were:

- Vinegar soaked wheat berries - new flavor note.
- Soy sauce soaked wheat berries - less bitter, full flavor.
- 50/50 Wheat / soy bean blend - hint of flavor typical of coffee.

Generally, based on the indications from the experiments, it is felt that an acceptable hot beverage can be made from CELSS ingredients using the American Harvest type of cyclonic oven for roasting. Additional effort is necessary to confirm these findings and to optimize ingredients and

procedures.

Additional thoughts on approaches include use of leaves or greens for an infusion technique such as used for tea; and, perhaps, use of other materials such as dried sweet potatoes.

APPENDIX B
PRELIMINARY INFORMATION ON MAKING
PUFFED SNACKS

PRODUCTION OF PUFFED SNACK PRODUCTS

Pending optimization of formulations to cope with the performance characteristics of available CELSS products and ingredients, micro-gravity, and equipment restrictions, the preparation of snack items such as puffed wheat and soy in a CELSS environment appears feasible.

The principle on which successful puffed snacks are formed is the conversion of moisture trapped in food particles or formed pieces, into steam under relatively well controlled conditions. Rapid heating or depressurization of preheated particles, in conjunction with barrier coatings or case hardened surfaces have been the traditional technique. Examples include popcorn as an example of rapid heating, and puffed whole grain cereals as an example of puffing by rapid decompression.

The sources of heat for puffing include deep fat frying, convected hot air, and microwaves. Screw-type extruders are frequently used to facilitate manufacture of puffed items from doughs or other homogeneous mixtures by providing mechanical energy and controlled heat to mix, gelatinize and pressurize the mix, which puffs as it undergoes decompression on exiting the die. Depending on weight and cube constraints, it would appear that convected hot air, microwaves, and extrusion should be compatible with CELSS.

CELSS puffed snacks should not require the shelf life demanded of commercial products, which should simplify formulation and packaging. The principal challenge anticipated will be in product development and defining process parameters.

The patent literature on puffed foods is extensive. A more comprehensive review should be undertaken. Preliminary review indicates that many CELSS-available products/ingredients have been successfully used in making puffed snacks as follows:

White Potato - dried flour, cooked potato solids, precooked-dehydrated potato, potato starch, and dextrose

Wheat - Whole wheat, ground wheat, wheat flour, and wheat starch

Soybean - Defatted soy protein, soy oil, and soybeans

Sweet potato - Sweet potato dices, sweet potato flakes, and sweet potato flour

Additional ingredients that could be made from these plants to provide flavor, variety, or extended functional properties to puffed snacks are as follows:

White Potato - Vinegar, Citric acid, sugar

Wheat - Bulgur, vinegar, citric acid, dextrins, dextrose, and gluten

Soybean - Whipping agents, yogurt, tofu, and glutamates
Sweet potato - Sweet potato syrup

Illustrative of approaches to microwave puffed products are those of Lazarus (1990) and Van Hulle et al. (1983). A brief description of each, with comments relating to CELSS operation follows:

Lazarus, C.R., U.S. patent 4,965,081 (1990)

A dry mix is prepared comprised of;

- a) 60 - 94.5% by weight of starch (wheat or potato)
- b) 3 - 9% tapioca starch (need to confirm its need or determine a suitable substitute such as wheat or potato starch, or soy whipping agent)
- c) 1-6% malto-dextrin (wheat or potato)
- d) 1.5-3% pregelatinized starch (could be wheat or potato, wheat gluten, or soy whipping agent)
- e) 0-15% flavoring or seasoning ingredients (could include; vinegar, citric acid, dried yogurt, and sweet potato syrup. Use of vinegar would reduce amount of water needed for mixing.

These ingredients would be mixed with water in a heat-extruder to yield a non-expanded, translucent product that is cut to desired shape and air dried to a moisture content of 5 to 20% by weight. This product can be puffed by hot air or microwaves to a "cooled" volume 6 to 20 times its initial volume. Potential variations to this procedure could include heated batch mixing and pasta-type extrusion, or incorporating a heating function into the grinder/extruder. The wide range of ingredients possible with this procedure enables considerable freedom in preparation.

Van Hulle, G.J., Anker, C.A., and Franssell, D.E., U.S. patent 4,409,250.

Puffable dough pellets are prepared from a mixture of native starch and pregelatinized starches, sucrose (could be sweet potato syrup), salt, and water. The mixture is cooked until all the starches are gelatinized (an extruder is preferred, but a vessel analogous to a steam kettle with agitator would be adequate), and then dried at low temperature to a final moisture content of about 12%. Ideally, the composition of the pellets, ready for puffing, might be as follows: starches - 77%, sweetener - 8%, salt - 3%, and moisture - 12%.

These pellets are blended into a paste-like puffing medium consisting of sweetener (about 75%), oil, and flavoring agents. This mixture (about 170 g in a 1.5 L container is heated in a microwave oven at full power for 2 minutes, stirred, then microwaved 30 sec. more. Pellets, when cooled, are 2 to 5 times their original size, and are coated with a glaze prior to consumption. According to the patent, the purpose of the puffing medium is to improve uniformity during microwave heating.

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13. ABSTRACT (Maximum 200 words) Based on the CELSS production of only four crops, wheat, white potatoes, soybeans, and sweet potatoes; a crew size of twelve; a daily planting/harvesting regimen; and zero-gravity conditions, estimates were made on the quantity of food that would need to be grown to provide adequate nutrition; and the corresponding amount of biomass that would result. Projections were made of the various types of products that could be made from these crops, the unit operations that would be involved, and what menu capability these products could provide. Equipment requirements to perform these unit operations were screened to identify commercially available units capable of operating (or being modified to operate) under CELSS/zero-gravity conditions. Concept designs were developed for those equipment needs for which no suit-able units were commercially available. Prototypes of selected concept designs were constructed and tested on a laboratory scale, as were selected commercially available units. This report discusses the practical considerations taken into account in the various design alternatives, some of the many product/process factors that relate to equipment development, and automation alternatives. Recommendations are made on both general and specific areas in which it was felt additional investigation would benefit CELSS missions.				
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